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ABSTRACT

This educator guide provides background information on Wilbur and Orville Wright and activities on aeronautics that provide templates for building the 1900, 1901, and 1902 Gliders and the 1903 Flyer. Activities include: (1) Early Aviation; (2) Your First Interview; (3) Your First Report; (4) Build a Model of the 1900 Glider; (5) Questions on the 1900 Glider; (6) What Would You Design?; (7) Build a Model of the 1901 Glider; (8) Forces on the 1901 Glider; (9) Questions on the 1901 Glider; (10) Wrong Ideas; (11) The Wrights' Wind Tunnel; (12) Operate the Wrights' Tunnel; (13) Build a Model of the 1902 Glider; (14) Compare the 1900, 1901, and 1902 Gliders; (15) Prices Then and Now; (16) Build a Model of the 1903 Flyer; (17) Balancing Forces; (18) Center of Gravity; (19) How Far Did They Fly?; (20) How To Launch the Flyer; (21) Write a Press Release; (22) Design a Mission Patch; and (23) Be an Inventor. (MVL)

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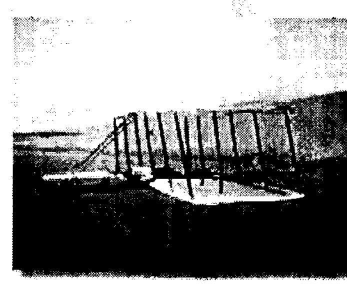
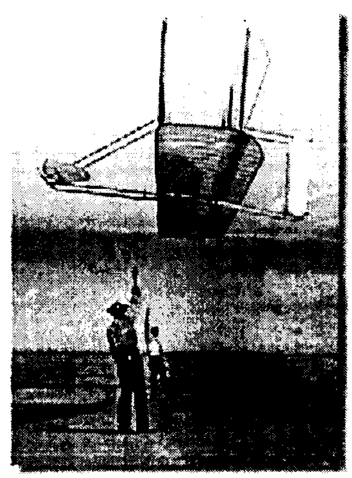
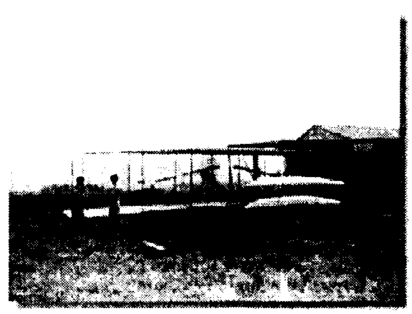
Learning to Fly: The Wright Brothers' Adventure







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Learning to Fly:
The Wright Brothers' Adventure
A Guide for Educators and Students With
Activities in Aeronautics

National Aeronautics and Space Administration

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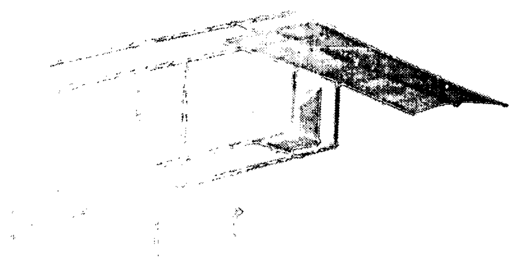

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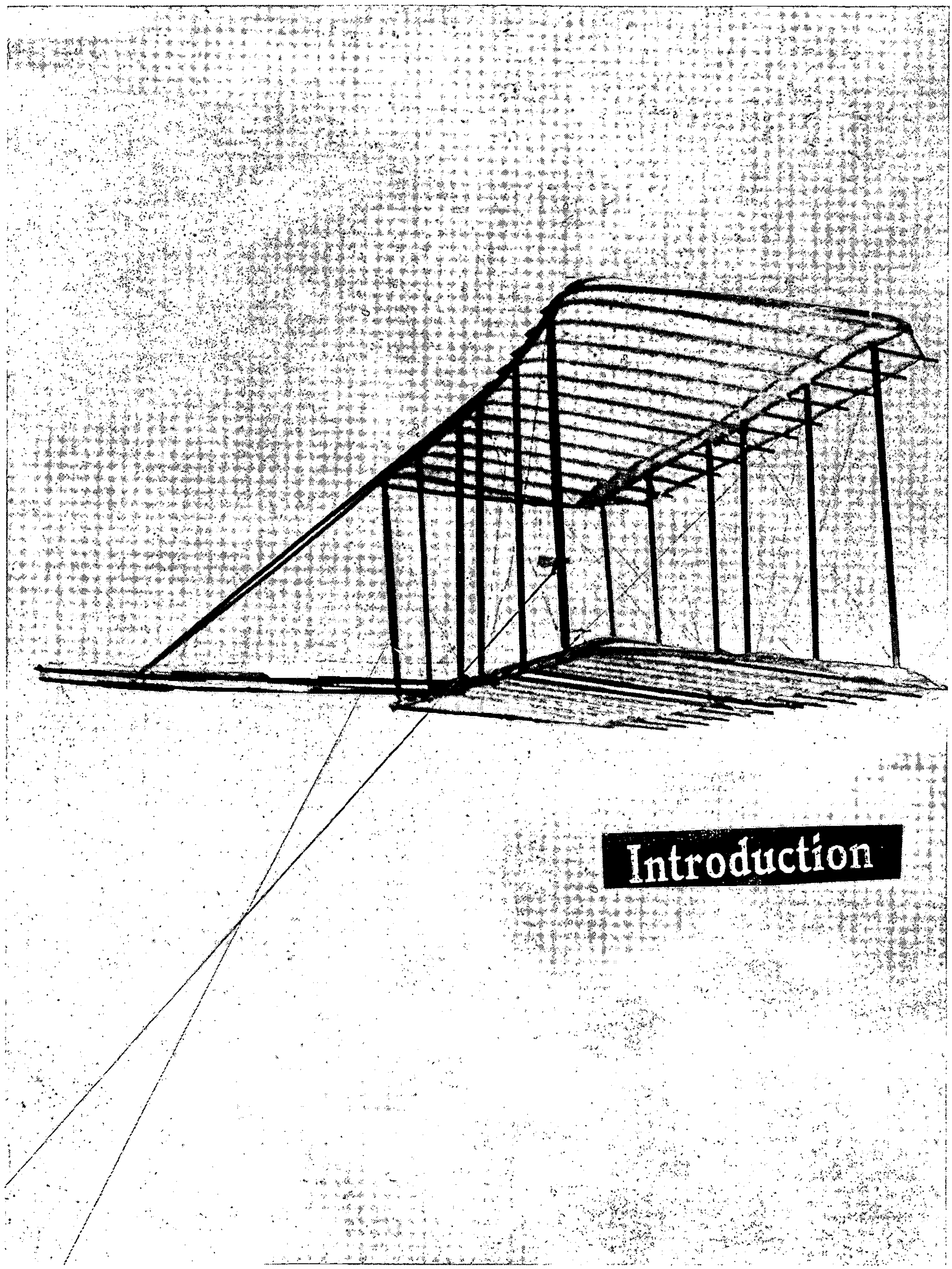
National Science Standards **Activity Matrix**		Evidence, Models, and Explanation	Change, Constancy, and Measurement	Form and Function	Understanding About Scientific Inquiry	Transfer of Energy	Motions and Forces	Abilities of Technological Design	Science as a Human Endeavor	Nature of Science	History of Science
Activity 1	Early Aviation				X		X		X		X
Activity 2	Your First Interview							X	X	X	
Activity 3	Your First Report			X			X	X	X	X	
Activity 4	Build a Model of the 1900 Glider			X				X			X
Activity 5	Questions on the 1900 Glider	X	X	X			X	X			
Activity 6	What Would You Design?	X	X	X				X			
Activity 7	Build a Model of the 1901 Glider				X			X			X
Activity 8	Forces on the 1901 Glider	X					X				
Activity 9	Questions on the 1901 Glider	X			X				X		
Activity 10	Wrong Ideas				X					X	X
Activity 11	The Wrights' Wind Tunnel	X	X	X				X			
Activity 12	Operate the Wrights' Tunnel	X	X	X	X			X		X	
Activity 13	Build a Model of the 1902 Glider			X				X			X
Activity 14	Compare the 1900, 1901, and 1902 Gliders	X		X			X	X			
Activity 15	Prices Then and Now		X		X						
Activity 16	Build a Model of the 1903 Flyer			X				X			X
Activity 17	Balancing Forces	X		X	X		X	X			
Activity 18	Center of Gravity	X	X		X		X				
Activity 19	How Far Did They Fly?		X		X						
Activity 20	How To Launch the Flyer	X				X	X				
Activity 21	Write a Press Release							X	X		
Activity 22	Design a Mission Patch								X		X
Activity 23	Be an Inventor				X			X	X		

NCTM National Mathematics Standards **Activity Matrix**		Problem Solving	Communication	Reasoning	Math Connections	Number and Number Relationships	Computation and Estimation	Patterns	Algebra	Statistics	Geometry	Measurement
Activity 1	Early Aviation											
Activity 2	Your First Interview											
Activity 3	Your First Report											
Activity 4	Build a Model of the 1900 Glider											
Activity 5	Questions on the 1900 Glider											
Activity 6	What Would You Design?									X	X	
Activity 7	Build a Model of the 1901 Glider											
Activity 8	Forces on the 1901 Glider		X							X		
Activity 9	Questions on the 1901 Glider											
Activity 10	Wrong Ideas											
Activity 11	The Wrights' Wind Tunnel											
Activity 12	Operate the Wrights' Tunnel		X			X		X		X		X
Activity 13	Build a Model of the 1902 Glider											
Activity 14	Compare the 1900, 1901, and 1902 Gliders										X	
Activity 15	Prices Then and Now	X		X		X						
Activity 16	Build a Model of the 1903 Flyer											
Activity 17	Balancing Forces											
Activity 18	Center of Gravity		X	X			X				X	
Activity 19	How Far Did They Fly?	X				X						
Activity 20	How To Launch the Flyer											
Activity 21	Write a Press Release											
Activity 22	Design a Mission Patch											
Activity 23	Be an Inventor											

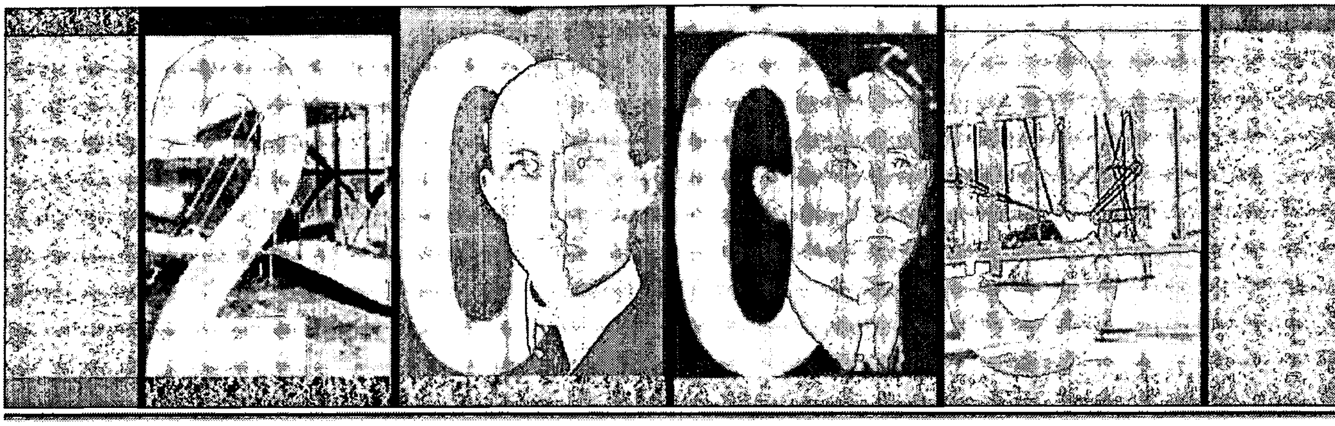
Contents

A note to teachers: Students who will complete the role-playing activity (section II) should skip section I and start with "The Society." All activities are on their own page for ease of duplication. Model activities begin on page 39.

For more information on the Wright Brothers' visit wright.nasa.gov.



Introduction



Flight According to Principle

One very cold and windy morning on a North Carolina beach, a lonely group of men huddled on the sand near their pride and joy: a kitelike contraption, built of cloth and wood and outfitted with bicycle parts. On the count of three, with the motor turning and heavy wind gusting, one man started to run alongside and guide the craft; in an instant, the pilot lying on the wing steered the craft to flight a few feet above the ground. The aircraft wobbled forward in the air for no more than 12 seconds, and settled triumphantly back to the ground. To an outsider, it would seem like a modest achievement. But it was the first time in history that an aircraft propelled by a motor and controlled by a pilot had left the ground. It was a moment that Wilbur and Orville Wright had labored to achieve for nearly 5 years.

On December 17, 2003, the world will celebrate the 100th anniversary of the first flight of the Wright Flyer. Before 1903, some people had flown gliders without engines; some had piloted lighter-than-air craft like hot-air balloons. Now a pilot would have the power to fly an aircraft at will, over long distances. No one could know in 1903 how that power would change the world.

Today we are so used to seeing jets in the sky, we forget that people were not always able to fly like birds. Some early aviators thought that building wings like those of birds would be enough to accomplish flight. The Wright Brothers, on the other hand, knew that flying would not be so simple. They were willing to think and work—and scratch their heads in perplexity—and think and work again for years to accomplish that first flight:

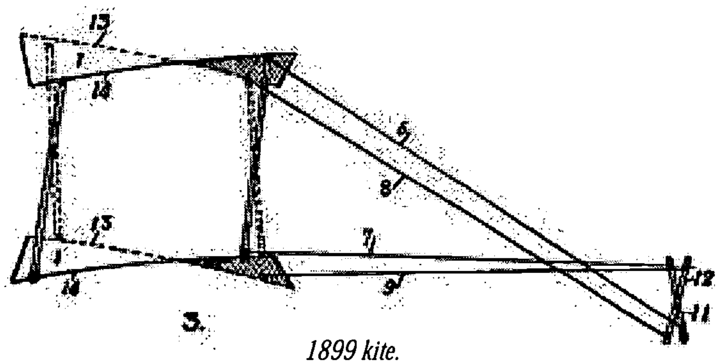
> *"... I would hardly think today of making my first flight on a strange machine in a 27-mile wind ...*
> *I look with amazement upon our audacity in attempting flights with a new and untried machine under such circumstances. Yet faith in our calculations and the design of the first machine, based upon our tables of air pressures, secured by months of careful laboratory work, and confidence in our system of control ... had convinced us that the machine was capable of lifting and maintaining itself in the air ..."*
>
> *—Orville Wright, from "How We Made the First Flight"*

In the early days of aviation, flying was extremely dangerous. Many daredevils were killed trying out crazy new flying machines. Otto Lilienthal, the German hang glider and foremost authority on aeronautics, had just been killed in one of his gliders in 1896 when the Wrights started to become interested in the idea of a flying machine. When Wilbur heard about Lilienthal's accident, he quickly read everything he could find about aircraft and wrote to the Smithsonian Institution for information on aeronautical research.

Lilienthal was a great influence on the brothers; he was not just a daredevil. He advocated using piloted gliders to learn about aerodynamics. He is considered to be the first person to design heavier-than-air aircraft carefully and deliberately. He developed many functioning gliders and was famous around the world. The brothers adopted his thoughtful approach to designing aircraft. Like Lilienthal, every time they made an innovation, it was well thought out.

"To invent an airplane is nothing. To build one is something. But to fly is everything."
—Otto Lilienthal

The brothers were also lucky enough to be able to correspond with Octave Chanute, another very important pioneer and author of "Progress in Flying Machines," published in 1894. Chanute was a civil engineer in his sixties when he began to study the problems of aviation. He designed and built gliders himself, so he had useful advice to offer the Wright Brothers. In fact, the correspondence between Chanute and the brothers shows many of the problems they had, and how they gradually solved them, one by one. Control of a flying aircraft was the most difficult problem to solve in the early days. Pilots often got hurt when their gliders did uncontrollable things.



1899 kite.

When the brothers observed soaring birds, they noticed that birds change the shape of their wings as they glide. Wilbur Wright had an extremely important insight about aircraft: he realized that a flying machine had to be controllable in all three axes of its motion: roll, pitch, and yaw. He came up with a technique he called "wing-warping," using a wing shaped like a long box that could flex its shape like a bird flexes its wing. Twisting the wings would change the direction of flight. In 1899, he and Orville constructed a 5-foot kite to test this idea. As predicted, when Wilbur used the control cables to twist the kite, it rolled left and right. Wilbur and Orville knew they were onto something.

In 1900, the brothers decided to build a large glider to test their theories about flying. Kitty Hawk, North Carolina was chosen as the test site because of its constant strong winds, sand for soft landings, and few trees. The glider was successfully flown as a kite, and on the last day of the "testing season," there was finally enough wind to fly the aircraft as a piloted glider and demonstrate roll control through wing-warping.

In 1901, the brothers returned to Kitty Hawk with a new glider that they had built at their bicycle shop. Their new aircraft had the same basic design as the 1900 aircraft, but it was larger to provide more lift to carry a pilot in lighter winds. In fact, it was the largest glider ever built and weighed about 100 pounds without the pilot.

Even though the new glider had flown up to 300 feet in a single glide, it did not perform as well as the brothers had expected. It only developed one-third of the lift that was predicted by data from Otto Lilienthal, and the drag was greater than predicted. The brothers modified the curvature of the wing, but this only slightly improved the glider's flight. Their test flights that year ended with a crash that rewarded Wilbur for his efforts with bruises and a black eye. At the end of 1901, the brothers were frustrated, and Wilbur remarked that humans would never learn to fly within the brothers' lifetimes.

The brothers began to question the aerodynamic data from Lilienthal on which they were basing their designs. They came up with another extraordinary idea. They built their own wind tunnel, one of the first in the United States, and used it to test their models. They found that the previous data from Lilienthal were in error and that their own data more correctly described the way gliders flew.

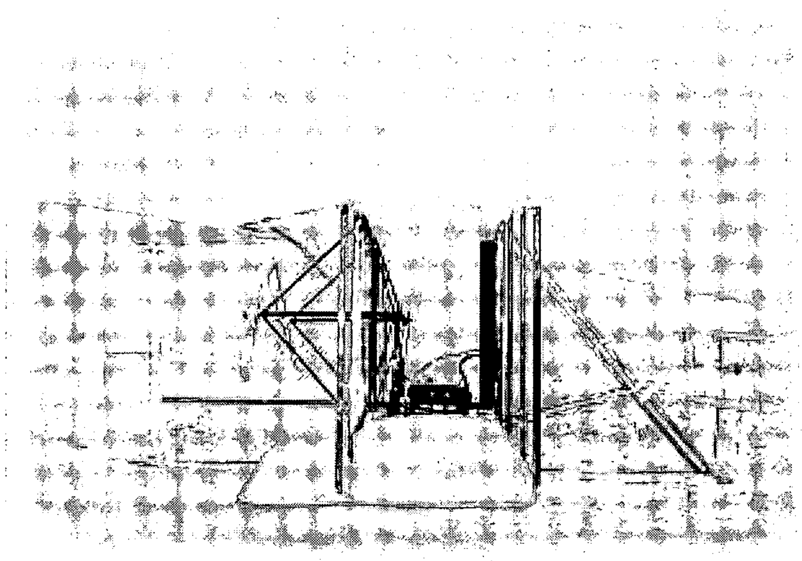
In 1902, Wilbur and Orville returned to Kitty Hawk with a new aircraft based on their new data. This aircraft had about the same wing area as the 1901 aircraft, but its wings were long and thin and it had a new movable rudder at the rear. The movable rudder worked with the wing-warping to keep the nose of the aircraft pointed into the curved flight path. With this new aircraft, the brothers completed flights of over 650 feet. This machine was the first aircraft that had active controls for all three axes: roll, pitch, and yaw. At the end of 1902, the brothers knew that all they needed to do was develop a motor and propellers and they would have the first successful airplane.

The Wrights could not find a manufacturer who would meet their requirements for a lightweight engine with sufficient horsepower, so they built their own 12-horsepower engine in just 6 weeks. They also created the first working aircraft propellers. In September 1903, they returned to Kitty Hawk with their new powered aircraft. With the pilot and the motor, the 1903 aircraft weighed a little over 700 pounds. On December 17, 1903, the brothers finally made four successful flights. After more than 5 years of solving problem after problem, Wilbur and Orville Wright had conquered powered flight.

But the brothers' work didn't end there. The 1903 airplane was only the first, and crudest, working airplane. It was very difficult to fly, especially since it tended to pitch down nose first into the ground. It took quite a bit more time and effort to develop a fully controllable craft.

By the end of 1904, the Wrights were making flights of several minutes at Huffman Prairie in a new aircraft with a new 18-horsepower engine. The brothers tried to solve the pitch problem by adding 200 pounds of ballast to the airplane, but the craft was still hard to control and difficult for the engine to lift.

In 1905, the brothers decided to keep the same engine, but to redesign the airframe. They increased the size of the elevator and rudder, and moved them farther from the center of gravity of the craft, increasing the overall length from 18 to 28 feet. This increased the torque produced by these control surfaces and provided greater control of the aircraft. The airplane's weight was reduced to nearly that of the 1903 airplane. The brothers continued to use a catapult system, first tried in 1904, to aid with takeoff.



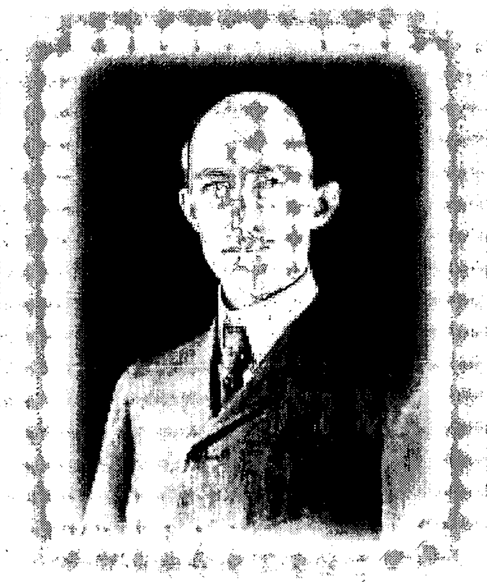
These improvements solved the last lingering problems. After 7 years of effort, the brothers had finally eliminated the pitching effect that had plagued the 1903 craft and built the first practical airplane. Little more than a decade later, in World War I, airmen and flying aces of many nations would embrace the airplane and entrust their lives to it.

About Wilbur and Orville

The Wright Brothers were raised in Dayton, Ohio, a few years after the Civil War. Their parents were Susan Catharine Wright and Bishop Milton Wright, a minister in the United Brethren Church. Both parents were talented, college-educated scholars who loved to learn. The boys' father was intellectual, and their mother was also mechanically gifted.

These qualities were inherited by the brothers and fostered by their life at home. Orville remarked, "We were lucky enough to grow up in an environment where there was always much encouragement to children to pursue intellectual interests; to investigate whatever aroused curiosity." The older brother was thoughtful and quiet; the younger brother was playful and adventurous. The two became lifelong best friends, always confiding their thoughts and plans to each other.

His father said of Wilbur, "In memory and intellect, there was none like him. He systemized every thing. His wit was quick and keen. He could say or write anything he wanted to. He was not very talkative. His temper could hardly be stirred. He wrote much. He could deliver a fine speech, but was modest."



Wilbur Wright

Wilbur was an excellent student, but circumstances such as his mother's illness and his own health prevented him from graduating from high school or attending college. But he and Orville found their own way in life anyway, using their imaginations and ingenuity.

Orville Wright

Orville, the younger brother, was more mischievous than Wilbur. He was a little like Mark Twain's Tom Sawyer; he was always coming up with a new scheme. He was adventurous and became a champion cyclist. While Wilbur would sit and read everything that fell into his hands, Orville was out in the world finding a lot of interesting things to get involved in.

The brothers had always liked mechanical things, especially the flying toys they had as children. When they were very young men, they built their own printing press using a tombstone and buggy parts and printed their own newspaper. At one point, Orville printed a newspaper called the *Tattler* for a young classmate, the poet Paul Laurence Dunbar.

When the brothers discovered bicycles, they began repairing them and eventually opened the famous Wright Cycle Company repair shop, where they produced their own bicycle models, the Van Cleve and the St. Clair. The bicycle shop became the brothers' workshop to build airplane parts—the parts that eventually flew on the first airplane.

When the brothers finally achieved their goal of powered flight, some people didn't understand the meaning of what they had done. Some found it hard to believe that a couple of "bicycle mechanics" could have succeeded where other distinguished would-be flyers had failed. By 1908, Wilbur and Orville had convinced the public that they had attained the goal that so many had tried to reach.

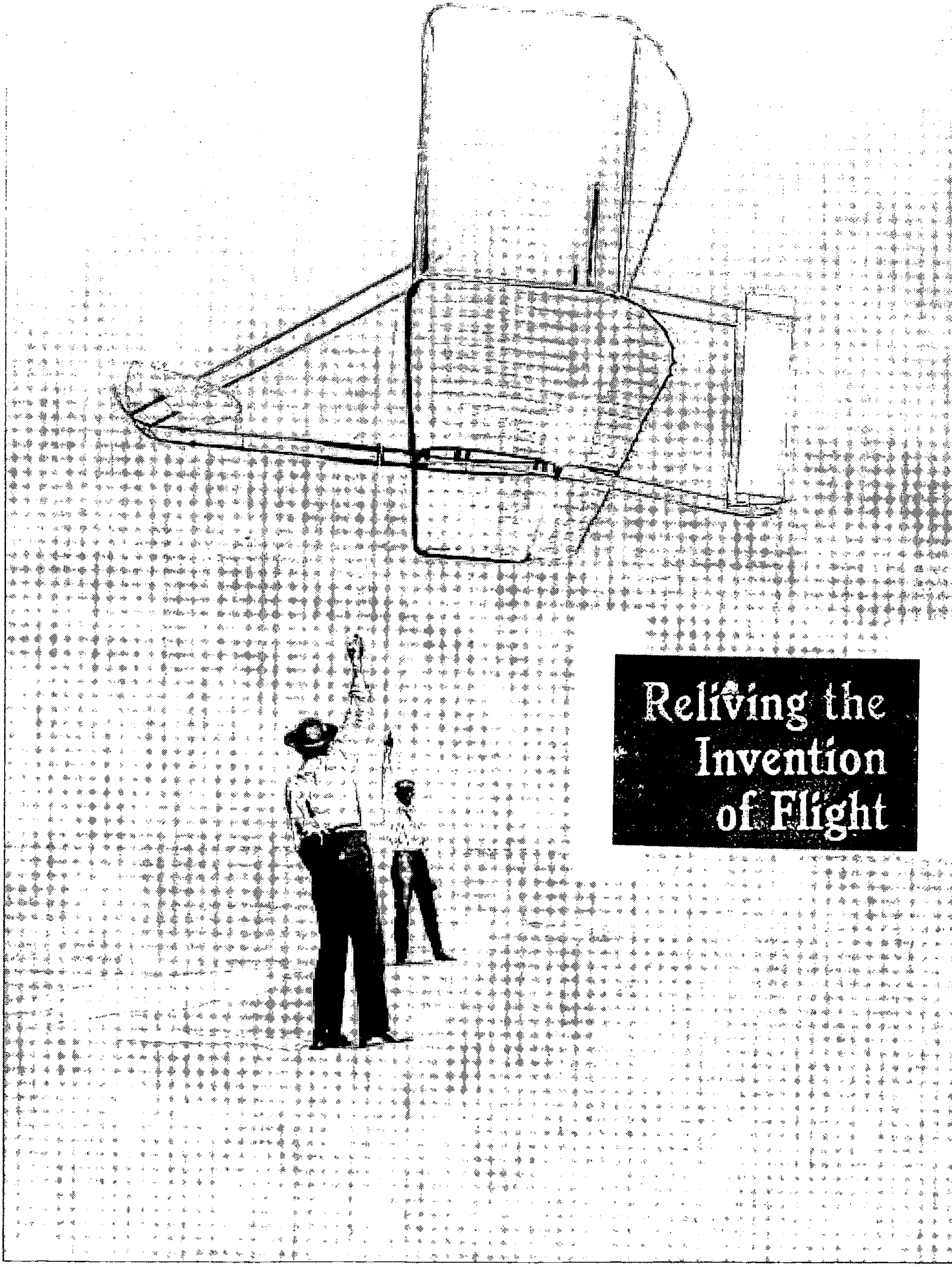
At one point, Wilbur amazed onlookers on the ground by flying around the Statue of Liberty and following the Hudson River to Grant's Tomb. This would be a shocking thing to see for the first time, if you'd only seen seagulls do it before. How brave and confident would you have to be to fly around the Statue of Liberty in your own homemade flying machine? The ambition, the curiosity, the studiousness, and not least, the bravery of the Wright Brothers were all needed to dare to fly.

Not long after the Wrights' success, in 1912, Wilbur died of typhoid fever at age 45. Orville sold the Wright Company, built an aeronautics laboratory, and returned to inventing. He also stayed active in the public eye, promoting aeronautics. He served for 28 years on the National Advisory Committee for Aeronautics (NACA), which was the forerunner of the National Aeronautics and Space Administration (NASA).

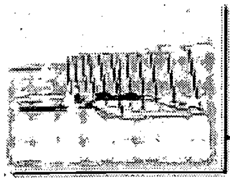

Wright Cycle Shop, Dayton, OH, 1909.

In 1930, Orville received the first Daniel Guggenheim Medal. This award, awarded for "great achievements in aeronautics," was established in 1928 by the Daniel Guggenheim Fund for the Promotion of Aeronautics. It is still awarded today to individuals for outstanding contributions. Orville Wright died in 1948 at the age of 76 in Dayton, Ohio.

Although neither had more than a high school education, the Wright Brothers were able to use the math and science they had learned to accomplish what is considered to be the most influential achievement of the 20th century. Some people even said that more education would have "ruined" the Wrights. However, Orville never agreed with that view. On the contrary, he said, a better scientific education would have helped them to do their work more easily.



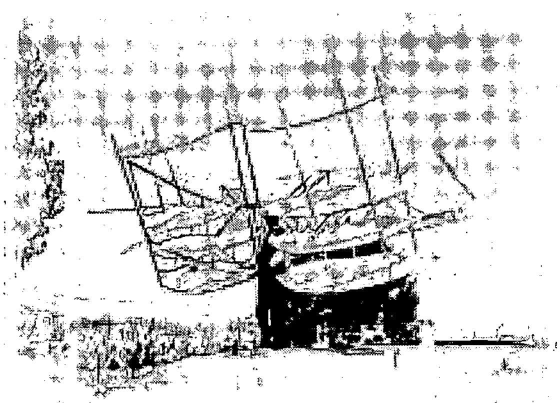
Reliving the Invention of Flight



The Society

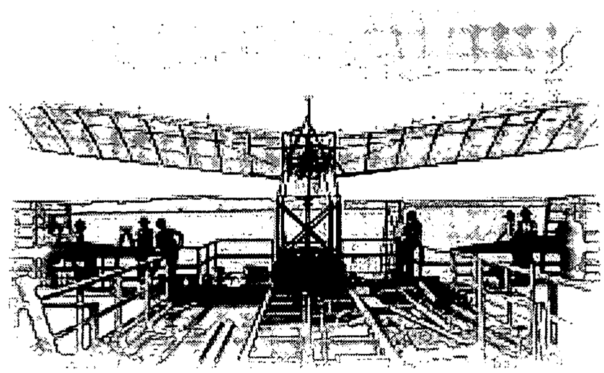
The year is 1900, and you are employed by the Cincinnati Scientific Society, a group of about 100 progress-minded people who are interested in learning about the latest advances in science and technology. Some of the members are very wealthy and regularly sponsor lectures, studies, and expeditions. At the Society meeting last month, Mr. Pierpont reported that his cousin from Dayton had written him about her neighbors, two bicycle salesmen named Wilbur and Orville Wright. People were saying that they were making a large glider in the back of their bicycle shop. In talking with the Wrights, Mr. Pierpont's cousin had learned that they were attempting to invent a flying machine.

This is just the kind of thing the Society is interested in. Society members had avidly read reports about the gliding experiments of the German Otto Lilienthal, who was killed when his glider went out of control and crashed in Germany in 1896; about the Englishman Percy Pilcher, who died the same way in 1899; and about the Americans Octave Chanute and Samuel Langley. Mr. Sidney Krause makes a motion that the Society send an investigator to report on the efforts of the Wright Brothers. The motion passes unanimously; you are selected to be the investigator. The Society gives you strict instructions to report only the facts and not to mention the name of the Society in your investigations. (Society members want to avoid the appearance of being out to steal anyone's ideas. They are just interested in science.) Mr. Pierpont gives you the address of the Wrights and their shop, and you set off for Dayton the next morning.

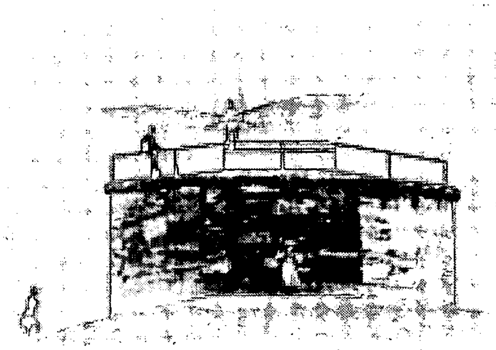


Chanute showing off the multiplane soaring machine "Katydid."

Courtesy of the National Air and Space Museum, Smithsonian Institute. Negative 1A-20406 A494771 (http://www.smithsonian.org/).



Langley's "Great Aerodrome" perched aboard a houseboat on the Potomac, just before a disastrous launch that tumbled the aircraft down into the river.



Lilienthal's flight station near his home in Steglitz (today part of Berlin).

Courtesy of Archive Otto-Lilienthal-Museum (www.lilienthal-museum.de. Inquiries are directed to LilienthalMusuem@t-online.de).

Activity 1—Early Aviation

Before you go to Dayton to investigate the Wright Brothers, it is important to do some research and get some background information. You need to go to the library and/or the Internet and find out about the progress of attempts to build a flying machine up to the year 1900 (try searching under terms like "early aviators" on the Internet). Write a short paragraph about each of the following and their accomplishments up to 1900:

1. Otto Lilienthal

2. Octave Chanute

3. Samuel Langley

See whether you can answer the following questions:

1. Why do you think some of these early pioneers were using gliders instead of powered aircraft? Why didn't their craft have engines?

2. What was the record for distance and time aloft by a manned glider in 1900?
   a) 20 feet and 2 to 3 seconds
   b) 100 feet and 5 to 6 seconds
   c) 500 feet and 8 to 10 seconds
   d) Over 1300 feet and 12 to 15 seconds

3. Why was gliding so dangerous at the time?

4. Why do you think Chanute chose to test his gliders at the Indiana Dunes on the southern shore of Lake Michigan?

5. How far is it from Cincinnati to Dayton? How do you think you might have travelled from Cincinnati to Dayton in 1900?

Activity 2—Your First Interview

Now that you know something about the state of flying machines in 1900, pretend that you are a reporter for the Dayton Daily News. You are being sent to interview the Wright Brothers. What questions do you think you would want to ask them about what they are attempting to do?

A. 1.

2.

3.

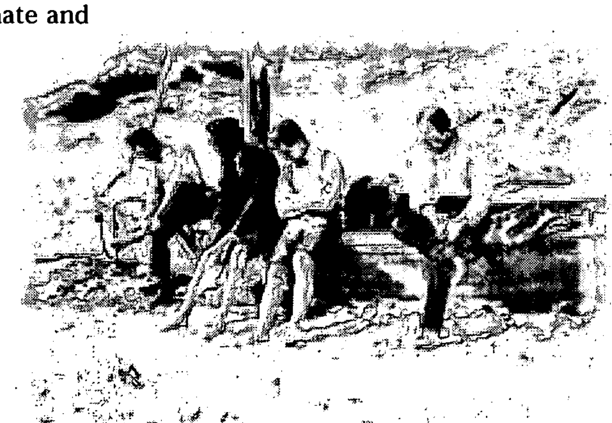
4.

5.

6.

B. If you are working in a class, team up with a classmate and see how your questions compare.

C. Discuss how you think the Wright Brothers might answer your questions.



News reporters waiting for the Wright Brothers to fly.

Meet the Wrights

Having been appointed by the Society to learn about the flying experiments of Wilbur and Orville Wright, you travel by train to Dayton. The trip takes about 2 hours, and when you arrive in Dayton, you ask for directions to the Wright Cycle Shop located on West Third Street. You catch the streetcar as directed.

Instead of going directly to the cycle shop, you decide to talk first with the neighbors. You run into a bunch of kids playing in the street and ask them what they know of the Wright Brothers. "They can fix anything," says one youngster. "They're good with bicycles," says another. "I like their kites!" pipes in another.

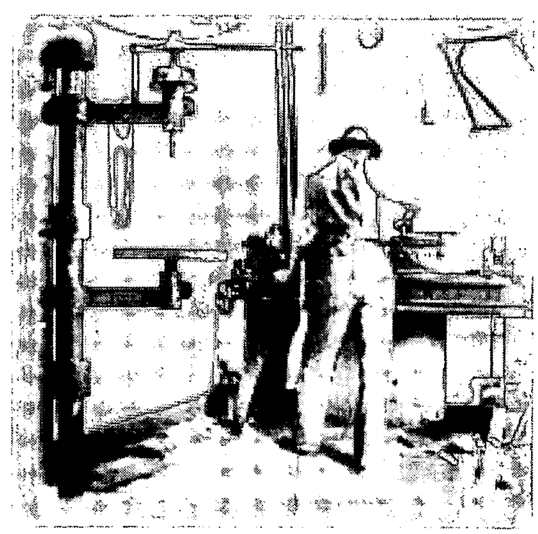
This is what you came to hear. "Last year, Wilbur made the biggest, best kite!" a boy declares. "It had two wings, was 5 feet across, and had four strings to it, one to each corner. When he pulled on the strings, the kite twisted and dove through the air. He could make it go any direction and he just about dove it into us kids. It really scared us!"

You thank the kids. Near the bicycle shop, you introduce yourself to a lady sitting on her porch. Does she know the Wrights? "Indeed I do, ever since they was little," she says. "Oh, they was always up to somethin', they was. They used to publish their own newspaper. Now they fix and sell bicycles. They really don't talk too much," she continued. "I hear tell they're buildin' some big flyin' contraption in their shop, but I ain't seen nothin'. I'd ask, but they pretty much like to keep to theirselves." You thank her, and go over to the cycle shop.

As you enter the shop, a tall man with sharp features comes out of the back room and introduces himself as Wilbur Wright. He asks you if he can help you, and you pretend to be interested in a bicycle. He shows you several makes, including some that he and his brother Orville designed themselves.

As you look at bicycles, you talk about a number of things. A shorter man in a derby hat comes in and Wilbur introduces him as his brother, Orville. As you talk about bicycles and transportation in general, you mention something about Octave Chanute and glider flights on the Indiana dunes. The eyes of both brothers light up at this, and they mention that they too have done a bit of research on the subject of flight. Wilbur says the key to success is being able to control a craft in the air. "The lack of control," says Orville, "cost Lilienthal and others their lives." The brothers say that they plan to carry out some experiments in North Carolina in the fall, but don't offer any more details. You shake hands and leave the shop.

Before you return to Cincinnati, you decide you are just too curious; you can't resist trying to get a look at whatever's in the back of the cycle shop. You wait until evening and slip around to the back of the shop. Looking in through a dirty window, you see the biggest kite or glider you ever saw. Although it's difficult to make out in the dim light, you see that it has two wings, one above the other. The wings must be 15 or 20 feet in length! At last, afraid of being discovered, you head for the train station and manage to catch the last train of the night back to Cincinnati.



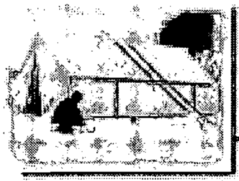
Wilbur Wright working in the Wright Cycle Shop.

Activity 3—Your First Report

1. From what you learned on your trip to Dayton, why do you think Wilbur was flying a large kite in the summer of 1899? What do you think he learned from doing it?

2. Having arrived back in Cincinnati after visiting the Wrights, you must make a written report to the Scientific Society. What are the key points that you would put in your report?

3. Why do you think the Wright Brothers are headed to North Carolina? What kind of conditions do you think they are looking for to carry out their glider experiments?



1900: Kitty Hawk

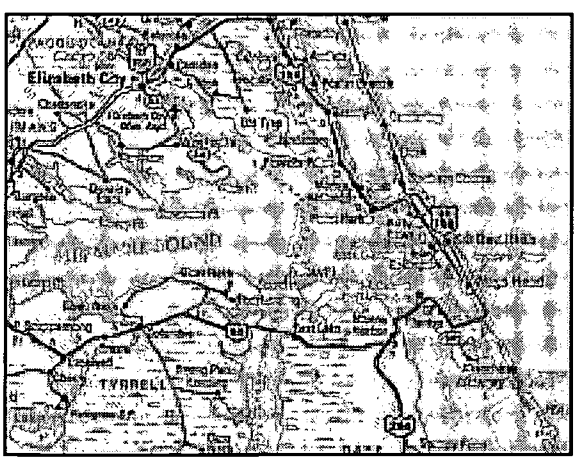
Having visited the Wrights in Dayton, you make your report to the members of the Society. Everyone is extremely interested in the craft being built in the back of the shop; the members excitedly discuss the possibilities of human flight. Mr. Pierpont's cousin says that the Wrights' sister Katharine told her that they are going to a place called "Kitty Hawk" in September. This sparsely populated North Carolina spot has high sandy hills, few trees, and almost continuous winds from the ocean: ideal conditions to test a glider.

The Society is anxious to send you there to learn of the experiments, but not in an obvious way. It is decided that you will apply for a temporary position with the U.S. Lifesaving Service, which has a station near Kitty Hawk. Several Society members help you to secure a job as a lookout while you also maintain your position and salary with the Society. The adventure and the money are too good to pass up.

Crew of the U.S. Lifesaving Service at Kitty Hawk, 1900.

You arrive in Elizabeth City, North Carolina, in August and catch a ride on the mail boat out to the Lifesaving Station near Kitty Hawk. If a shipwreck occurs, your crew's job is to brave the surf and rescue stranded sailors.

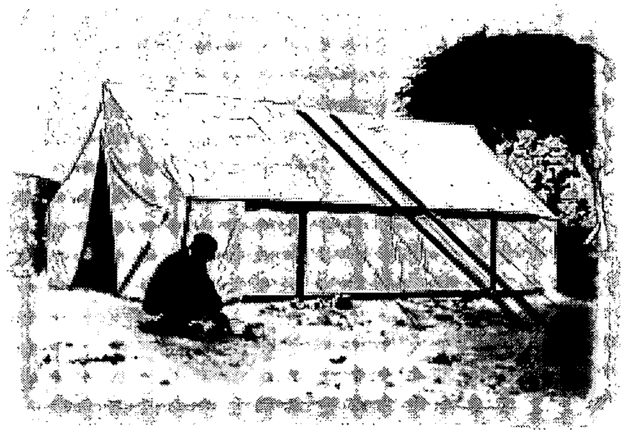
On September 13, Wilbur Wright arrives in Kitty Hawk and stays with William Tate, the local postmaster. Soon, Orville arrives and they set up a tent camp about a one-half mile from the Tates. You receive word that the brothers' kite has arrived, so you decide to visit their camp.



You introduce yourself to the Wrights as a lookout from the Lifesaving Station. Wilbur recognizes you from your visit to their shop in Dayton, and you tell him you are a college student from Cincinnati and were in Dayton visiting friends.

The brothers remember your interest in flight and proudly show you their creation. This is the same large craft that you saw in their shop. It has two wings about 17 feet long and 5 feet deep, one set about 4 feet above the other. Both wings are made of a tightly woven white material stretched over a light wooden frame. Wire bracing keeps the structure tight. A square structure that looks like a small wing made of the same white material is sticking out a few feet in the front. You note that the wings are arched. When you ask about the open space you see in the lower wing, Orville informs you that the pilot rides there, lying on his stomach, so it is indeed a glider. Due to light winds, they are testing the glider with chains to simulate the weight of a pilot. You ask permission to stay and watch, and they ask whether you'd be willing to help!

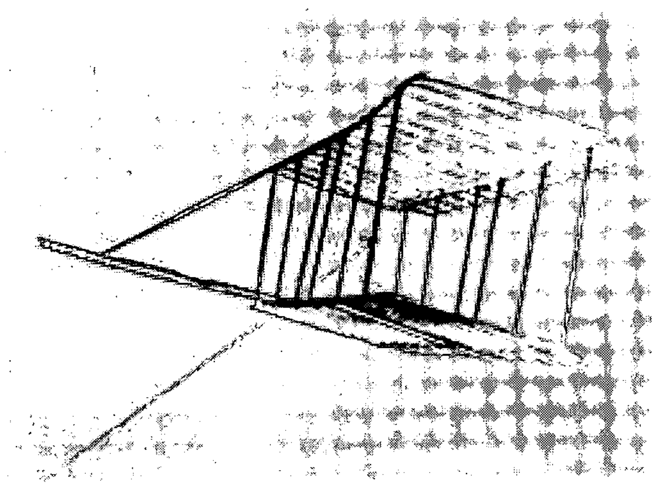
As strong breezes blow, the glider, which must weigh nearly 100 pounds with the chains, just floats in the air. You and Orville struggle to hold onto cables that act as kite strings; Wilbur is behind the glider pulling on another set of wires. As he pulls on one wire, the wings twist and the glider tilts and drifts to the side. When he pulls the other wire, the glider turns in the opposite direction. This is just like the kite the kids in Dayton had described to you. The control was truly wonderful! You want to stay all day, but your shift as a lookout is coming up. The brothers thank you for your help and invite you back.



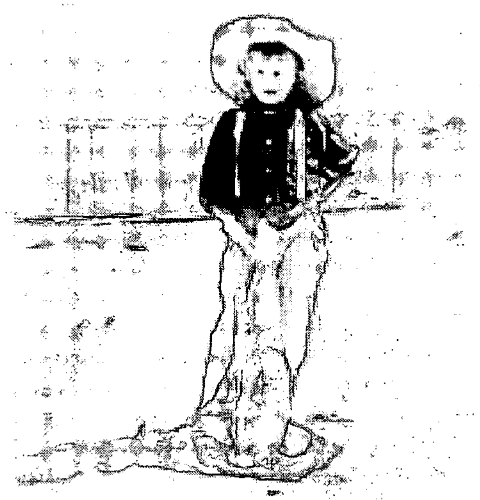
Wilbur Wright at first camp at Kitty Hawk, 1900.

You visit the camp a few more times, and you notice that the curvature of the small front wing is sometimes different, and this seems to cause the glider to fly at a different angle. You always see the brothers flying the glider as a kite, but the other men at the station tell you that one day they had seen Wilbur actually piloting the glider. On that particularly windy day, they say, he had glided for 10 to 20 seconds and covered 300 to 400 feet before suffering a minor crash landing.

Soon after, the Wrights pack up and return to Dayton, leaving their crashed glider in the sand; Postmaster Tate's wife washes the fine sateen fabric of the wings and makes dresses for her daughters. You take leave of the Lifesaving Station and return to Cincinnati to report to the Scientific Society.



The Wrights' 1900 Glider.



October 1900: 10-year-old Tommy Tate, son of Kitty Hawk postmaster William Tate, standing in front of the 1900 Glider with his drum fish. Tommy flew as a lightweight pilot on some of the Wright Brothers' glider flights.

Activity 4—Build a Model of the 1900 Glider

The Society asks you to make a model of the Wright's 1900 aircraft as a part of your report. Turn to page 41 and follow the instructions to make your model.

Activity 5—Questions on the 1900 Glider

Your report to the Cincinnati Scientific Society stimulates a lot of discussion. The members have many questions as they try to understand the Wrights' experiments. How do you think you would answer this sampling of their questions?

1. Why did the Wrights use a two-wing (biplane) arrangement?

2. What was the purpose of having the wings be curved or arched?

3. Why did the pilot of the Wright Glider lie down on the wing instead of hanging from the glider, as in Lilienthal and Chanute's gliders?

4. Why do you think twisting the wings caused the glider to drift left or right? How much did the wings twist? If they stayed twisted, do you think the glider would fly in circles or crash? Why?

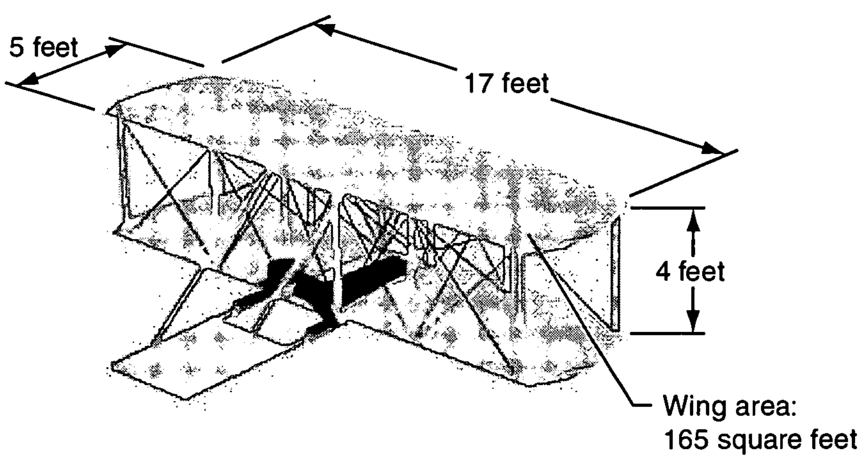
Activity 6–What Would You Design?

Orville told you that he and Wilbur are determined to create a flyable machine, and that to do this they are going to have to get more lift out of their craft so it can support a pilot. When you report this to the Cincinnati Scientific Society, the members start to debate about what they think is the best way to accomplish this. It is decided to have a contest to see who can produce the best design to improve upon the Wright Glider.

1. If you were to enter this contest, what specific changes would you make to give the 1900 Glider more lift?

2. How do you think each change would improve the original design?

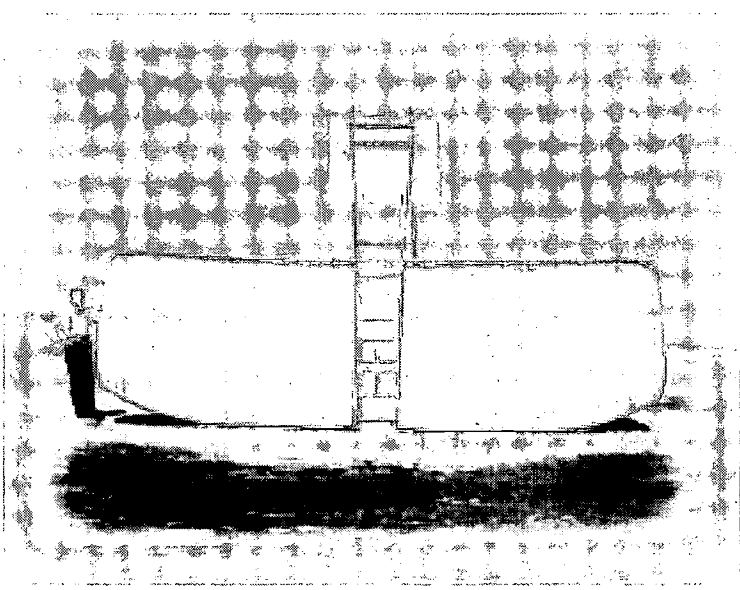
3. This is a drawing of the 1900 Glider. It had a wingspan of 17 feet and a wing area of 165 square feet. On another sheet of paper, draw a sketch of your proposed glider, showing a top view and a front view. Be sure to put dimensions on your sketch. How long, wide, and high will your glider be?



1901: The First Improvement

You are involved with various activities as secretary for the Cincinnati Scientific Society when a letter arrives in March from the cousin of Mr. Pierpont, the neighbor of the Wright Brothers. She has spoken with Katharine Wright, who told her that her brothers have constructed a new glider and intend to go to Kitty Hawk for testing much earlier than last year, leaving sometime in July. With anticipation, you arrange to return to the Lifesaving Station at Kill Devil Hills in late June to resume duties as a temporary lookout so you can observe the new trials.

The Wright Brothers arrive on July 10, 1901. This year, in order to be closer to their launch site at Kill Devil Hills, they move their camp about 4 miles south to the base of Big Hill. This puts them much closer to your station, and it's easier to observe their experiments.



The 1901 Glider.

The new glider is much bigger than the first. It still has two wings, but they are larger, each 7 by 22 feet. The total wing area is now 290 square feet, and the aircraft weight has doubled to 100 pounds. This would be the biggest glider ever flown! You have the opportunity to visit the brothers' camp a number of times to observe and assist with flights. Wilbur is the pilot on each trial. There are other visitors to the camp, and you are introduced to Mr. Octave Chanute and two assistants, who are there to observe as well as test a glider of their own.

The flights of the 1901 Glider are disappointing. Orville tells you that they had used the data from tables published by Otto Lilienthal to design the new wings, but the glider only produces about one-third of the expected lift. Could Lilienthal's data be wrong? Although there are frequent glides of around 300 feet, you notice other problems as well. The front rudder doesn't seem to do much to control the up-and-down pitch of the glider, and when the wings are warped to turn, the craft sometimes settles backward and spins out of control. In one of these crashes, Wilbur suffers minor injuries. After that, they only fly the aircraft as a kite.

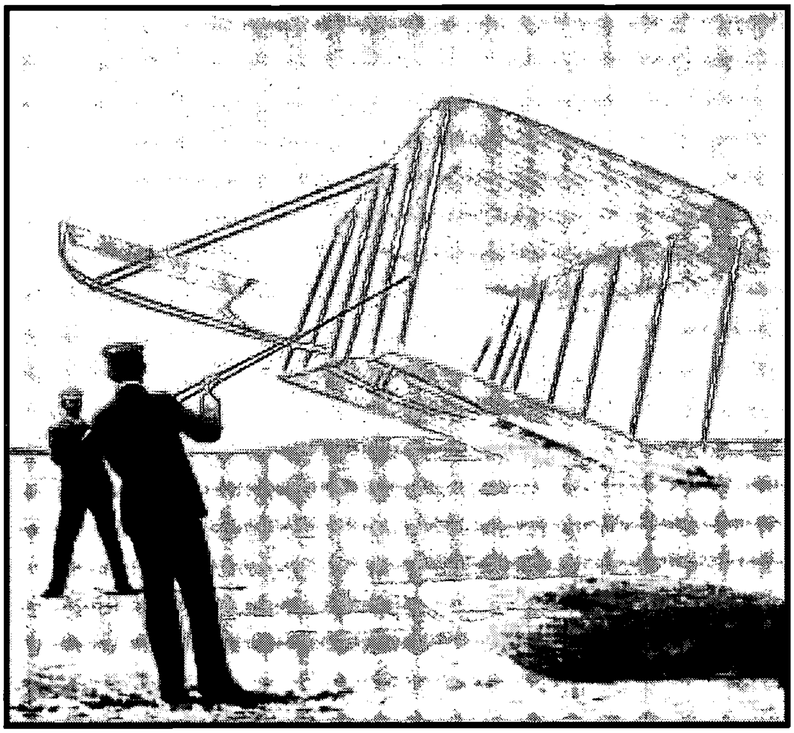
At the end of August, the brothers return to Dayton in disappointment. You stay on an additional week to compile your notes and then return to Cincinnati to report to the Scientific Society. You report that Wilbur has said that he believes that people will fly, but not in their lifetimes. After two summers of trials, the Wright Brothers are very discouraged.

Activity 7—Build a Model of the 1901 Glider

To make a model of the 1901 Glider for your report, follow the instructions beginning on page 48.

Activity 8—Forces on the 1901 Glider

The picture below shows the Wright Brothers at Kitty Hawk, NC, with their 1901 Glider being flown as a kite. It weighed 98 pounds and had a wingspan of 22 feet. The kite appears to be floating in the air, but it is actually being held motionless because the forces that are acting on it are "balanced."



1. You know that wind is needed to fly a kite, so draw an arrow on the picture to show which way the wind would be pushing on the glider.

2. There are three other forces that are acting on the kite. One of these is the lift caused by the wind acting on the wings of the glider. Draw an arrow to show the direction that this force acts on the glider.

3. The third force acts on you and all other objects on Earth all the time. It is called __________________. Draw an arrow to show the direction that this force acts on the glider.

4. Look at the men in the picture and see if you can determine the direction of the fourth force. Keep in mind that the glider is motionless, so the fourth force must act to balance out the other three forces. Draw an arrow to show the direction of the fourth force.

5. Do you see anything in the picture that shows that all the forces are canceling each other out? If yes, what is it?

6. If the speed of the wind increased, what would happen to the glider?

Activity 9—Questions on the 1901 Glider

The report of the summer of 1901's activities caused quite a stir in the Cincinnati Scientific Society. When you mailed sketches of the new craft back in July, many members had thought that the additional surface added to the wings would provide the lift needed. Clearly something was wrong.

1. Why do you think that the new glider with its larger wings failed to perform as expected?

2. If you were Wilbur or Orville Wright, what would you do at this point? Why would you do this?

3. To solve a problem, the Wright Brothers would only make a single change at a time. Why is this a scientific way to do an experiment?

Activity 10—Wrong Ideas

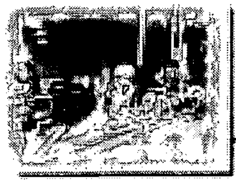
Advances in science are often hindered by making wrong assumptions, making assumptions based on incorrect information, or by not understanding information or data in the right context. The Wright Brothers thought the reason their 1901 Glider did not perform up to expectations was that Lilienthal's data, on which they had based their calculations, were wrong.

Choose one or more of the following ideas that were once accepted as correct in science. Find out who may have challenged these ideas and how our thinking changed as a result. Write down your answers.

1. The Earth is flat.

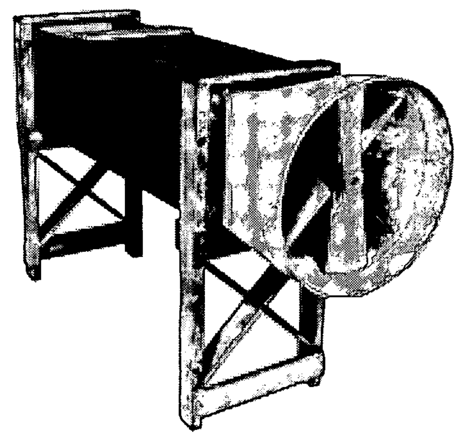
2. The Sun revolves around the Earth.

3. There are only four elements: earth, air, fire, and water.



New Data

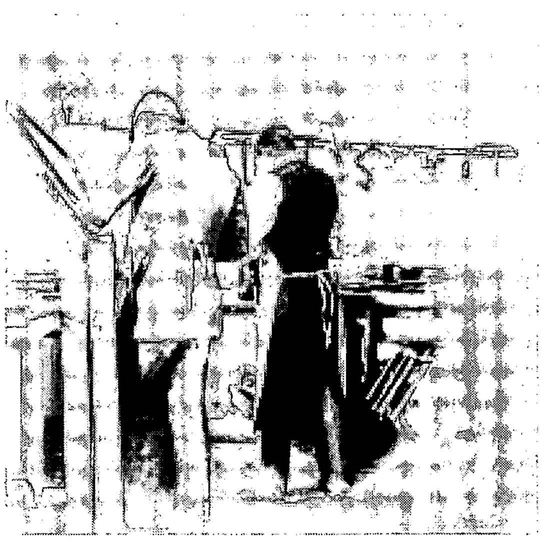
After your second season at Kitty Hawk, you resume your duties at the Scientific Society. Several members attend the meeting of the Western Society of Engineers in Chicago, where Wilbur Wright is a featured speaker. Upon their return they're eager to talk to you about his speech and your observations at Kitty Hawk. The members are impressed with the Wrights' scientific knowledge and their logical problem-solving approach. The positive reaction from the audience encouraged Wilbur in spite of the past year's disappointments. You will make another visit to Dayton soon to see how the investigations are going.



Reproduction of the 1901 Wright wind tunnel, the first wind tunnel to produce reliable aerodynamic data.

In December you correspond with Mr. Pierpont's cousin to find out what the brothers are up to. She responds that they have constructed some sort of device to measure the effectiveness of different wing shapes. She says that she even saw Orville riding on a bicycle with a wheel attached to the handlebars, with what looked like little wings on the wheel. She guessed he was testing the wings somehow.

You arrange to travel to Dayton in January. When you enter the shop, Orville greets you with pleasure. You tell him you are visiting friends on break from school and thought you would stop in and say hello. Orville invites you into the back room, where you see a bicycle with a wheel mounted flat on the handlebars. Upstairs, the brothers have set up a 6-foot-long box with a fan on one end, and a table with a number of small wing models.

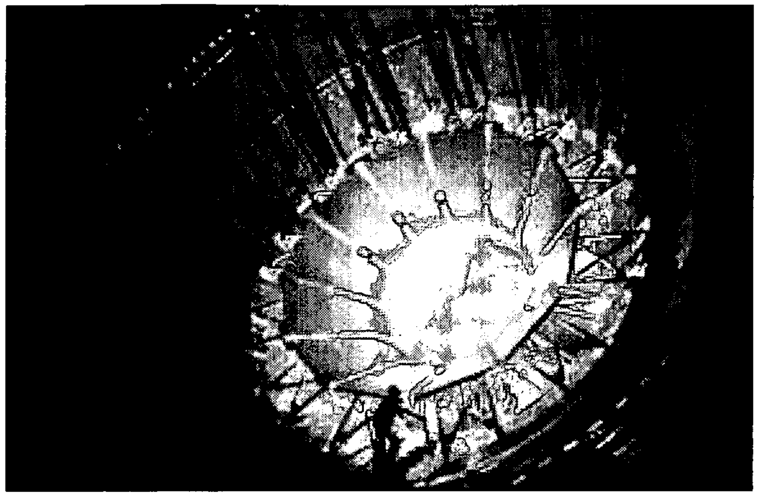


Orville Wright and Edward Sines at work in the Wright Cycle Shop, 1897.

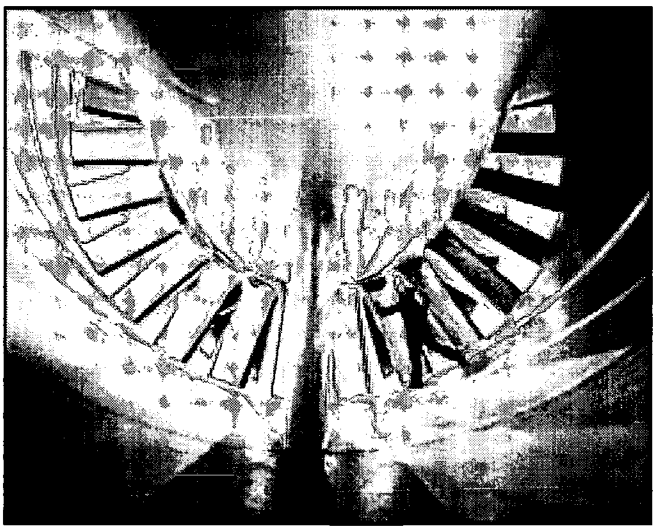
Orville explains that Wilbur's talk in Chicago had recharged their enthusiasm. They suspected that the second glider's poor performance might be due to errors in Lilienthal's data tables. To test this, Orville placed the wing shapes on a bike wheel mounted on a bike's handlebars, and rode off to provide wind. The angles of attack predicted by Lilienthal did prove to be in error. In fact, the Wrights discovered that the shape of the wing, viewed from above, is very important in the generation of lift. Lilienthal's data only applied to small, oval-shaped wings, while the brothers' wings were rectangular shaped. Orville and Wilbur decided that they needed to collect their own data.

Orville shows you the box they built for testing. A belt turns a large fan, which pushes air through the box, and a grid straightens out the flow of air as it enters the box. The brothers observe the testing through a glass window above the test area, where the wing shapes are mounted on a balance made of hacksaw blades and bicycle spokes (this box has come to be known as a "wind tunnel"). Orville says that they've tested a large number of shapes in several combinations, and with their new data they are designing a glider to try in late summer. You wish him luck, tell him that you hope to see him in the summer, and leave to catch your train back to Cincinnati.

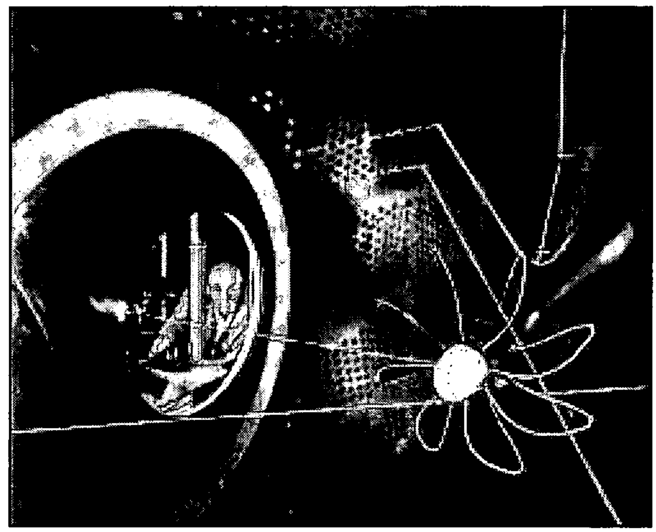
Modern Wind Tunnels



Inlet diffuser of a wind tunnel at NASA Ames Research Center. The inlet diffuser works like the grid that was used for "straightening" the wind in the Wright tunnel. Ames has the world's largest wind tunnel at its site in California.



Propulsion fan (like the fan to create airflow in the Wright tunnel) of the Transonic Wind Tunnel at NASA Langley Research Center (the fan blades of this older tunnel are made of wood). The first major U.S. wind tunnel was built at Langley in 1920.



Test section of a supersonic (high flight speed) wind tunnel at NASA Glenn Research Center. The white "lines" are laser beams that engineers use to measure the performance of the model. The Wrights used a bicycle-spoke balance to do the same job in their tunnel. A researcher is peering in at a window just as the Wrights did.

Activity 11—The Wrights' Wind Tunnel

The Wright Brothers are credited with a number of "firsts" in the science of aeronautics. One of these firsts was using a wind tunnel of their own design (a 6-foot-long rectangular box) to gather data and to design wing shapes (called airfoils). Wind tunnels are still used for many kinds of research. Some of them are very large; some are supersonic; some are very cold; and some simulate very high altitudes.

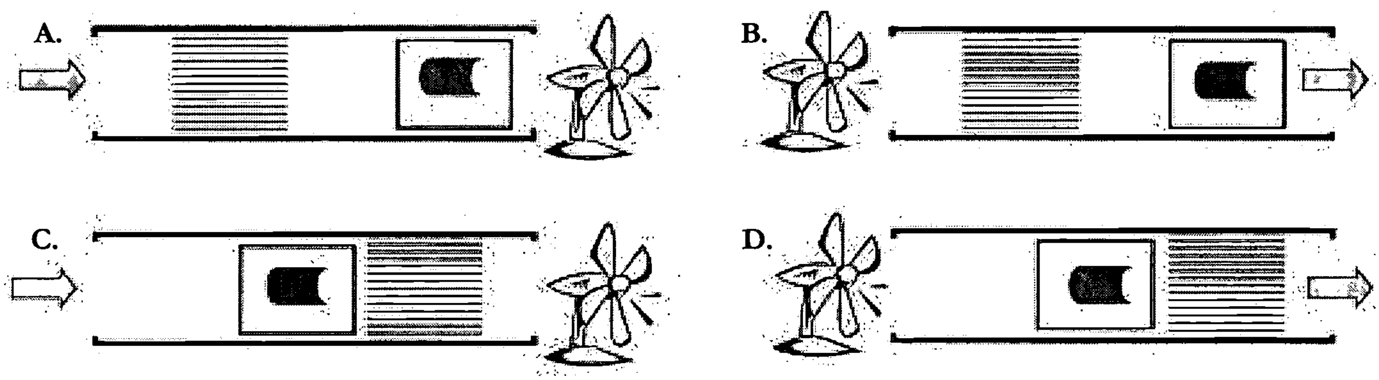
1. Why did the Wrights construct their own wind tunnel?

2. When they ran their tests, the Wrights only allowed one person in the room and that person always had to stand in exactly the same place. Why do you think they had to take this precaution?

3. A grid was placed in the end of the box where the air entered. What function would you guess this served?

4. What advantages are there to testing airfoils in a small box? (Try to list at least three.)

5. If you were to try to get good data on how well a wing design worked, which of the following wind tunnel arrangements do you think would be best?



What factors made you decide on this as the best design?

Activity 12—Operate the Wrights' Tunnel

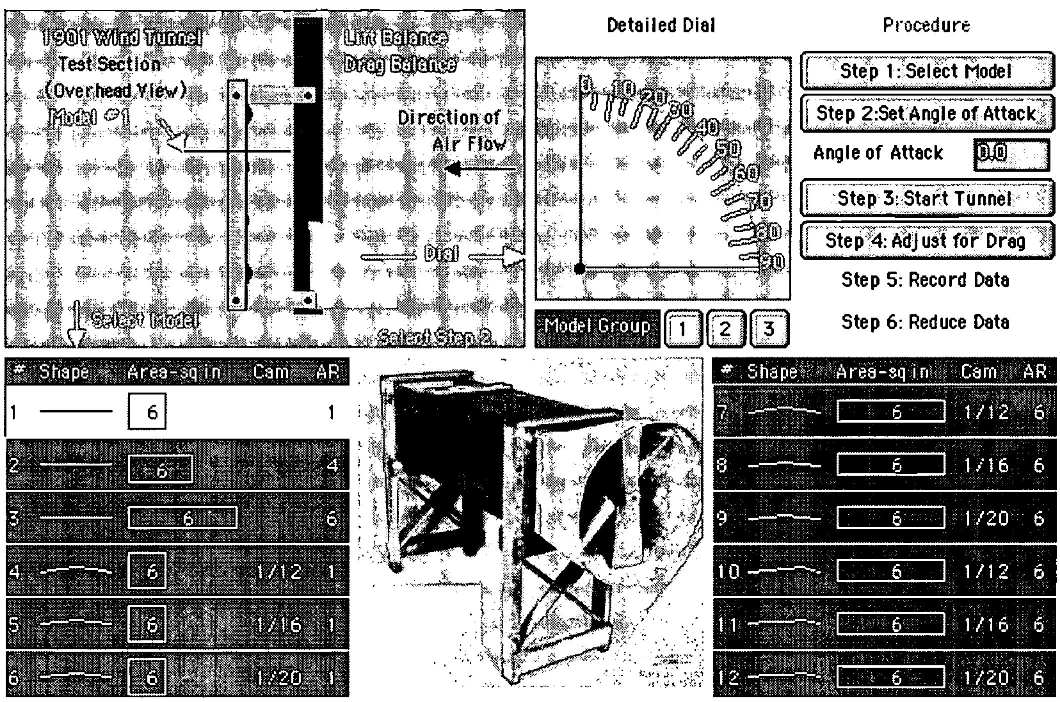
Wilbur and Orville didn't understand why their larger 1901 wing didn't provide the lift they expected. To find out why, they built their own wind tunnel and conducted almost 200 tests of wing shapes and combinations. The wind tunnel tests showed how air flowed over the airplane wing, and what effect the wing's shape had on the amount of lift that the airplane could generate. You can conduct these very same tests yourself in the very same kind of wind tunnel (only you will be using an online computer program). The wind tunnel test can be found at the following Web site:

http://wright.grc.nasa.gov/airplane/tunnlint.html

Interactive Wright 1901 Wind Tunnel

Glenn Research Center

We present here a Java applet derived from FoilSim which simulates the operation of the Wright 1901 Wind Tunnel.



Lift Data Form | Table of sin(a) | Graph Paper | Drag Data Form | Table of tan(a)

Airfoil images courtesy of The Franklin Institute Online - http://www.fi.edu/wright/index.html. Tunnel and balance images courtesy of Wright State University via OhioLINK Digital Media Center.

You can download your own copy of this applet by pushing the following button:

Download Applet

To operate the balance, follow these steps:

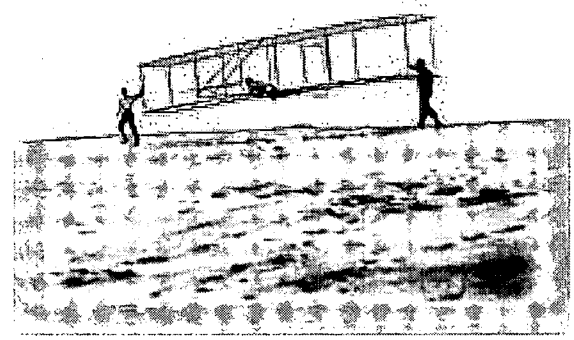
1. Choose a wing model to be placed in the tunnel from the menus at the bottom left and right.
2. Set the angle of attack by clicking on the Set Angle of Attack button and enter numbers in the box. Or use the mouse to move the arm in the diagram.
3. Start the tunnel with the Start Tunnel button.
4. Adjust for the drag caused by the balance with the Adjust for Drag button.
5. Record the reading on the Lift Dial. The greater the deflection on the Lift Dial, the more lift is being provided by the wing.

A. Which wing shape is better, short and wide (model 1) or long and thin (model 3)?
   1. Choose model 1, set the angle of attack to 3 degrees, start the tunnel, adjust for drag, and record the reading on the Lift Dial.
   2. Repeat this at angles of 6, 9, 12, 15, and 18 degrees.
   3. Now choose model 3 (which has the same area as model 1) and record the data for the same angles. You can get a copy of a form to record your data by pushing the "Data Form" button.
   4. Make a graph of your results. There should be two lines on your graph. Which wing shape is providing more lift? Which shape is better, short and wide or long and thin?

B. Which wing surface provides more lift, a flat surface or a curved surface?
   1. Choose model 3, set the angle of attack to 3 degrees, start the tunnel, adjust for drag, and record the reading on the Lift Dial.
   2. Repeat this at angles of 6, 9, 12, 15, and 18 degrees.
   3. Now choose model 9 (which has the same area as model 3, but is curved) and record the data for the same angles.
   4. Make a graph of your results. There should be two lines on your graph. Which wing is providing more lift? Which wing surface is better, flat or curved?

C. Which provides more lift, a more strongly curved surface (model 4) or a less strongly curved surface (model 6)?
   1. Choose model 4, set the angle of attack to 3 degrees, start the tunnel, adjust for drag, and record the reading on the Lift Dial.
   2. Repeat this at angles of 6, 9, 12, 15, and 18 degrees.
   3. Now choose model 6 (which has the same area as model 4) and record the data for the same angles.
   4. Make a graph of your results. There should be two lines on your graph. Which wing is providing more lift? Which wing surface is better, more curved or less curved?

1902: Success at Last



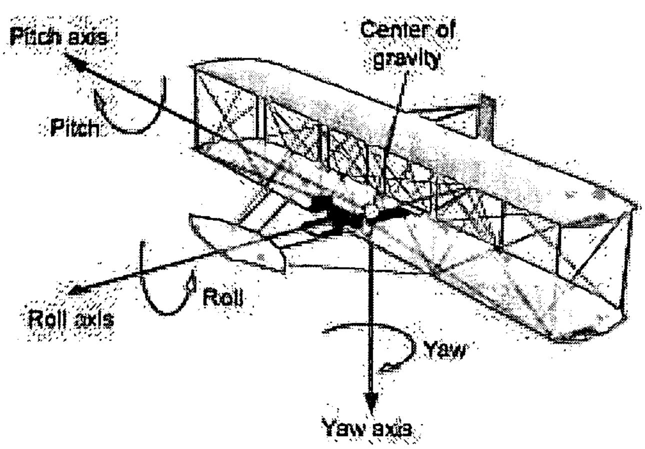
Testing the 1902 Glider.

When the Society hears of the Wright Brothers' logical approach to overcoming the 1901 disappointments and their successful wind tunnel trials, excitement builds about human flight. Arrangements are again made for you to resume your position as a lookout with the Kill Devil Lifesaving Station. Your friends at the station are glad to see you again.

At the end of August the Wrights arrive and rebuild their camp. When they uncrate and assemble their glider, it is indeed a changed machine. The wingspan has grown to 32 feet and the width has been decreased to 5 feet. A control device called a "hip cradle," which the pilot operates by moving his hips, controls the wing-warping. The front rudder has been modified to look more like a wing. In addition, a tail with two 6-foot-high vertical tails has been added. On your first visit, Orville explains that they are hoping the tails will give the pilot more control in turning. You help to carry the craft up the hill—it weighs a good 120 pounds.

The glider flies wonderfully, much better than the one last summer. A new problem, however, soon arises. In about one flight in fifty, the glider spins out of control and crashes after making a turn. The brothers make several adjustments, but nothing seems to help.

When you return in a few days, the brothers have removed the two vertical tails and replaced them with just a single tail. Wilbur has also rigged the tail to the hip cradle control that warps the wings. Now when the pilot shifts his hips to bank, the tail also turns. "Orville reasoned that in low-speed turns, the tail was acting like a vertical wing, providing a sideways force that caused the glider to spin," said Wilbur. "I thought up how to rig the wing-warping to the tail-turning." That's just one example of how the two brothers thought and worked so well together.



When Wilbur takes off, your jaw drops. The glider banks left and then right, rises up and down on command, and then glides to a smooth landing. They've done it! The brothers have achieved complete control in the air. You're watching the first machine in history that can be controlled in three dimensions: pitch, yaw, and roll.

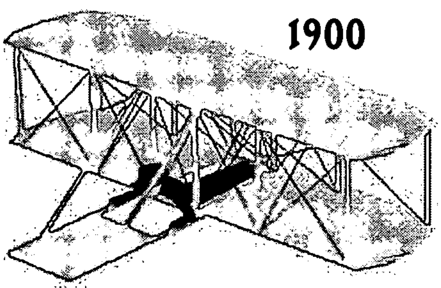
Over the next few weeks, the brothers make several hundred glides, becoming better and better at controlling their craft. You are sending glowing letters back to the Society and helping Orville develop some of the pictures he has taken. The brothers feel that they only need to add an engine and propellers and they will become the first in the world to fly a powered aircraft.

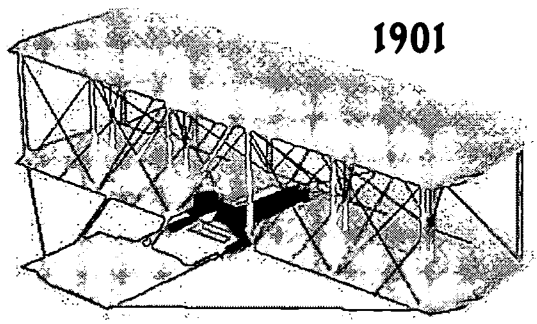
Activity 13—Build a Model of the 1902 Glider

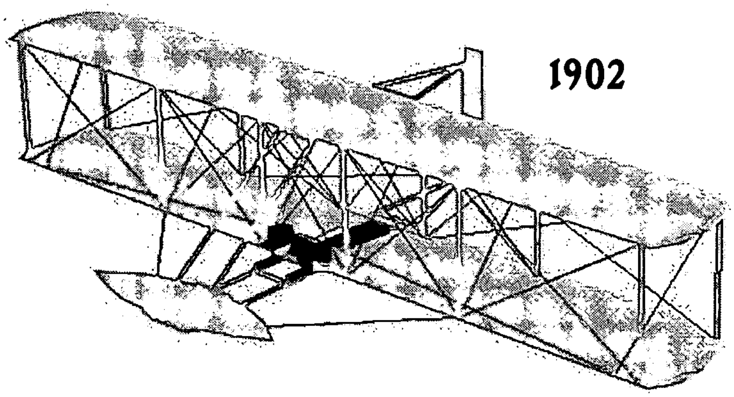
To make a model of the 1902 Glider, follow the instructions beginning on page 55.

Activity 14–Compare the 1900, 1901, and 1902 Gliders

Below are drawings of the gliders the Wright Brothers tested in 1900, 1901, and 1902. Notice that Wilbur Wright is the same size in all three, which means all three are drawn to the same scale.







1. Try to list five ways in which all the gliders are alike.

2. What are some of the ways that they are different?

3. The 1901 and the 1902 gliders both have about the same wing area and they weigh nearly the same. Why do you think the 1902 is a better glider?

4. Notice that in all three gliders, Wilbur is lying down. What do you think the effect would be if he sat up while flying them?

Activity 15–Prices Then and Now

The pictures at the Wrights' camp were captured by something called a "box camera." The Wright Brothers also took pictures on 5- by 7-inch glass plates, which they developed and printed themselves. Over 300 of these images are on display at the Carillon Historical Park in Dayton, OH.

The year that the Wright Brothers decided to build their first kite, 1900, was the year that a very popular box camera was offered for sale, the Eastman Kodak Brownie. Brownies were the first cameras most amateur photographers ever owned. Many of the first owners of Brownies were kids. Brownie cameras were sold, modeled, and remodeled (about 100 times!) for six decades. Your family probably owned one too!

The 1900 Brownie camera cost $1. In 1900, a laborer might have worked a month to earn $50. A professional might have earned $100 or $200 a month. Do you think the Brownie camera cost about the same amount (the same percentage of a monthly salary) for a buyer in 1900 as a $100 camera would cost us today?

Courtesy© Eastman Kodak Company.

1. If you made $100 a month in 1900, and a camera cost $1, what percentage of your monthly salary would it take to buy a camera in 1900?

2. If your yearly salary today is $36,000 and you want to buy a camera that costs $100, what percentage of your monthly salary would you have to spend? How does this compare to 1900?

3. The Wright Brothers had to buy all the food to stock their camp and ship it by boat and horse-drawn wagon. In 1900, a loaf of bread cost 5 cents. Today it costs about $1, or 100 cents. The price of bread has increased by 100 cents divided by 5 cents, or 20 times. Find out how many times these items have increased in price since 1900 by completing the table. You will need to find out today's prices.

Food	1900 price	Price today	Increase
5 pounds flour	13 cents		
1 pound butter	26 cents		
1 dozen eggs	21 cents		
1 gallon milk	27 cents		

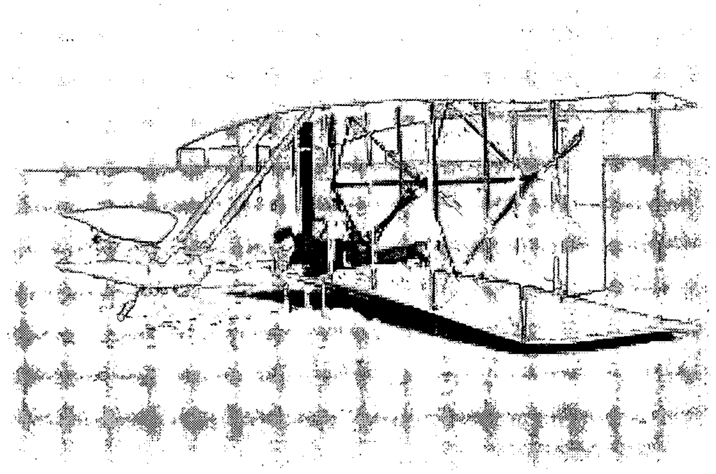
Which item showed the biggest change in price?

The Society thanks you for the report on the success of the 1902 Glider. They are also following the progress of Samuel Langley's flying research. Langley had successfully flown a steam-powered aircraft three-quarters of a mile and won a $50,000 government grant to develop a passenger-carrying powered aircraft. Society members wondered whether the Wrights could beat him on their small budget, having spent less than $1,000 so far.

You have been on this project for almost 3 years, and the Society president asks you if you want to continue. You say yes. By now you have come to admire the Wrights and their genius and want to see them succeed. You know that powered flight is moving closer to becoming reality.

The reports from Dayton are that the brothers had been trying to find an engine with at least 8 horsepower and weighing less than 200 pounds. They couldn't find an engine like that, or a company willing to make one, so with the aid of their bicycle mechanic Charlie Taylor, they have been building their own engine. You travel to Dayton to check on progress, and when you arrive, they are already testing it. In just 6 weeks, having never made an engine before, they have produced one weighing 179 pounds that develops 12 horsepower! They never cease to amaze you.

Orville tells you that they are having difficulty with the design of the propellers. There are no reliable data on air propellers, only on water propellers, which would not apply to an aircraft. "Our only solution," he says, "is to design our own!" You wish them luck and they say they hope to see you at Kitty Hawk in the fall. You return to Cincinnati wondering whether they will get it right.



Wilbur in the damaged flyer after his unsuccessful trial on December 14, 1903. His hand still grips the wooden control lever.

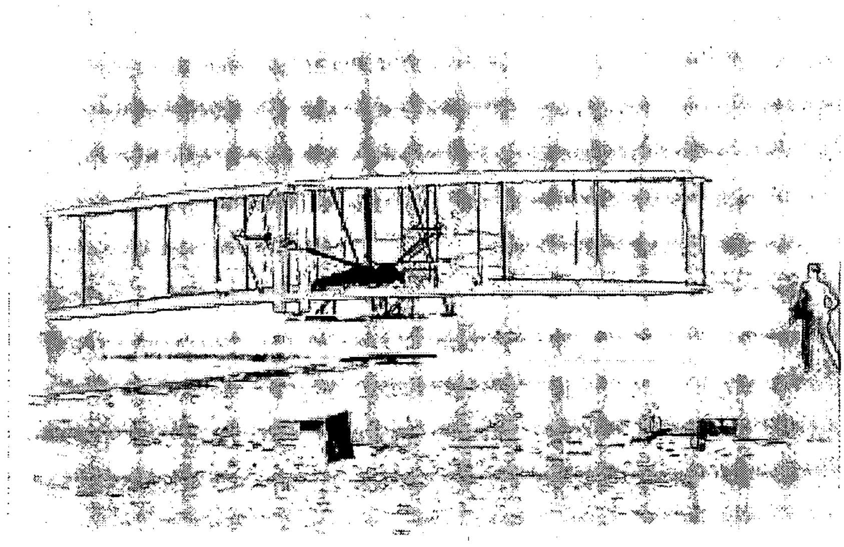
Further reports from Mr. Pierpont's cousin in Dayton indicate that the brothers intend to return to Kitty Hawk at the end of September, so once again, you head back to the Lifesaving Station. The Wrights arrive on September 25, 1903, and are glad to enlist your help in re-building their camp buildings and unpacking the crates holding the new craft. "This is the very first time we've seen it all together," comments Wilbur. "There just wasn't room in our shop." The aircraft looks like the 1902 model, but measures 40 feet from wing tip to wing tip and has twin rear rudders. On the lower wing opposite the pilot position is the motor, connected by chains to two long, thin propellers at the rear of the wing.

"We spent 5 months working on those propellers," said Wilbur. "Orville finally figured out that they needed to be shaped like rotating wings." Once the aircraft is together and testing begins, there are problems with the propeller shafts. Quick fixes don't work, so Orville travels back to Dayton to get new, stronger shafts.

He returns on December 11 and everything is ready to test on December 14. The brothers hoist their red flag, a signal for you and the Lifesaving crew to come help. The wind is not strong enough to launch from level ground, so the 60-foot launching track is set up on the side of Big Hill (the launching track consists of 15-foot sections of wooden rail, on which runs a launch cradle with bicycle hubs for wheels). The aircraft is pushed to the top of the track on its launch cradle. With the restraining rope in place, the motor is started and the propellers start to turn. Orville and Wilbur toss a coin to see who will be the first pilot. Wilbur wins and takes his position. He pulls the release rope, and the aircraft rolls on the cradle about 40 feet down the track, and starts to become airborne. Wilbur pulls up the nose a bit too sharply, and it stalls and settles back in the sand, breaking a few parts. It had been airborne just 3 seconds.

It takes some time to repair the damage, and on December 17, the red flag is hoisted again. It is very cold today, and the puddles on the way to the brother's camp are frozen over. The wind is blowing much harder than before. When the aircraft is set on the cradle, it is now Orville's turn to pilot. Orville has set up his box camera facing the end of the track and hands the squeeze camera bulb to John Daniels of your Lifesaving crew. Orville then gets into the craft and the rope is released. The wind is so strong that Wilbur runs alongside the craft to steady the wing as it takes off. Just as he lets go and the craft becomes airborne, Big John squeezes the camera bulb and snaps one of the most famous pictures ever taken. Orville flies for 12 seconds and lands a little over 120 feet from the end of the track. All of the people watching are cheering as you run to retrieve the airplane. You all shake hands and then go warm up by the stove before you carry the plane back up the track.

Three more flights are made, the longest being Wilbur's, which lasts 59 seconds and covers 852 feet. At long last, a man had flown a powered flying machine. As the brothers are getting ready for a fifth flight, a powerful gust of wind picks up the airplane and rolls it over and over. It is so badly damaged that more flights are out of the question. The Wrights thank everyone for their help, walk 4 miles up the beach to telegraph their father of their success, and pack up and return to Dayton to perfect their airplane.



The Wright Flyer takes off on the world's first successful airplane flight on December 17, 1903. Orville is at the controls, while Wilbur runs alongside.

Activity 16—Build a Model of the 1903 Flyer

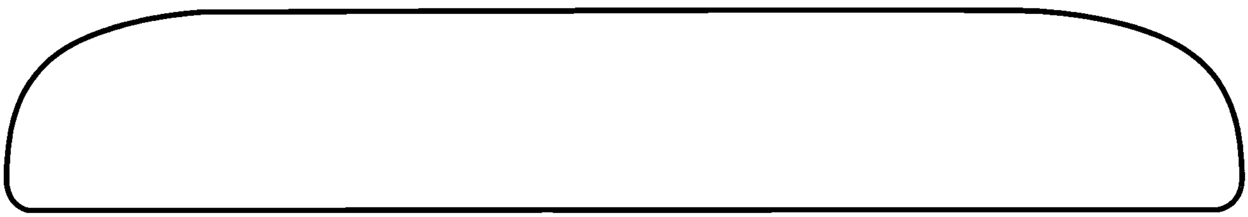
To make a model of the 1903 Flyer, follow the instructions beginning on page 63.

Activity 17—Balancing Forces

If you were either Orville or Wilbur Wright, and it came time to design a flying machine with an engine, where would you place the engine and where would you place the pilot? Do you think that the pilot should sit up or lie down on the wing? Don't forget that there had been numerous crashes in the brothers' gliders over the past 3 years. Give some serious thought to the reason or reasons for your decision.

The drawing below is a top view of the lower wing of the 1903 flying machine. Draw where you would put the pilot and the engine.

Back of wing



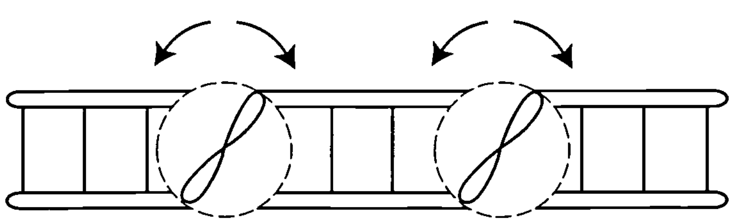
Front of wing

1. What are the advantages in the way you placed the engine and pilot?

2. What problems do you think might be created with your placement?

3. Does your pilot sit up or lie down? Why?

4. Circle the direction that each propeller needs to turn to create the least amount of torque (twisting) of the aircraft.



Activity 18—Center of Gravity

In constructing their 1903 Flyer, the Wright Brothers chose to place the engine on the wing next to the pilot. They felt that this would be safer for the pilot because the engine would not land on him if the flyer crashed. The problem that this created for them was one of balance. Neither Wilbur nor Orville weighed as much as the engine, and the wings needed to be level in order to have control of the plane. Try the following activity to see how to solve the problem:

Take a string and tie it around a 12-inch ruler in the exact middle. Now hook two paper clips together to represent the pilot and four paper clips together to represent the engine. Open up one of the end paper clips on each group as shown so that they can hang on the ruler (you can also cut the paper clip to size with a wire cutter). Hook the groups on either side of the center and then slide the paper clips along the ruler until the ruler hangs level.

When the ruler is level, the total weight of one set of paper clips times the distance from the center is equal to the total weight of the other set of paper clips times their distance from the center. Write down the inch readings for each group of clips.

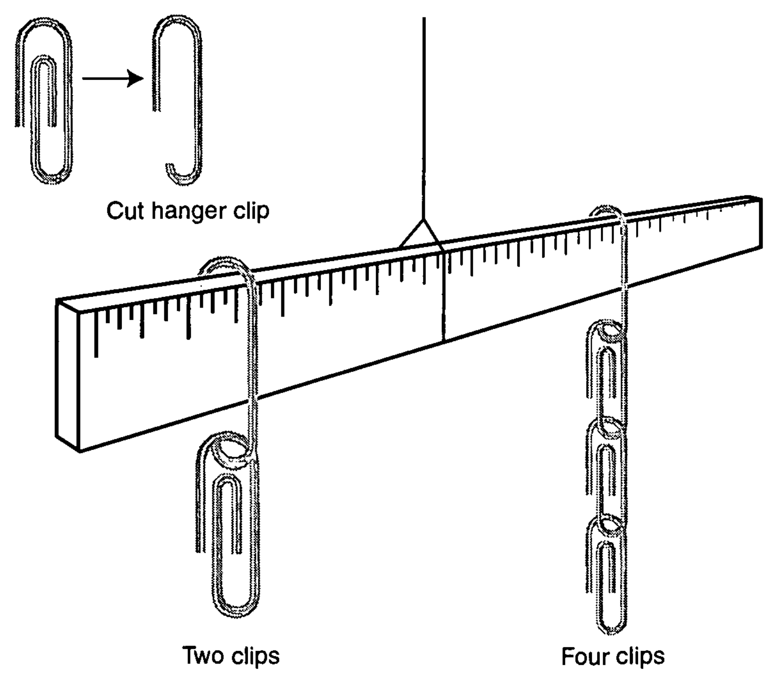
Two paper clips set at ____________ inches from the center

Four paper clips set at ____________ inches from the center

Since one group weighs twice as much as the other group, it should only be half as far from the center. Check the inch marks and see if this is true.

The Wright Brothers needed to stay near the center of the plane in order to control it, so rather than move farther out on the wing to balance the engine, they made the wings on the engine's side of the plane 4 inches longer than on the pilot's side. This caused extra lift force on that side to counteract the extra weight of the engine and keep the wings level!

You can simulate this by moving the four-paper-clip weight 1/4 inch farther away from the center so things are no longer balanced. Now, instead of moving the two-clip weight to rebalance, move the location of the string holding the ruler until everything is back in balance. Did you move the string toward the two-clip weight or the four-clip weight?



Activity 19—How Far Did They Fly?

Materials

Wooden ice cream sticks or craft sticks
Tape measure
Stopwatch or watch with a second hand

1. Have each person put his or her name on a wooden stick to use as a marker.
2. Go outside to the playground, a large field, or a baseball diamond and choose a starting point. This could also be done indoors in a gym or long hallway.
3. Each person takes a turn at placing their marker where they think 120 feet from the starting point would be, the distance of the Wright Brother's first flight. (These should all be placed along the same line from the starting point. You may want to lay a very long string down first to use as a guide, or you could use the foul line of a baseball field. Or each person could walk toward the same distant object.) Once placed, each person should stay by his or her marker so no one else steps on it.
4. When all the markers are in place, use the tape to measure off exactly 120 feet from the starting point and determine whose marker was the closest. Also, measure the distance each person was from the 120-foot mark and record these results in the table below. Once measured, be sure to remove all the sticks.
5. It took Orville 12 seconds to fly 120 feet, with Wilbur running alongside the airplane as it launched. See if you can run this fast. Time how many seconds it takes each person to run 120 feet and record the results.

Name	Distance from 120-foot mark	Time to run 120 feet
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		

Questions

1. Whose stick was the closest to the actual 120-foot mark? Do you think this is a very far distance to fly?

2. Could the Wright Brothers have flown . . .

   A. From home plate to first base on a baseball field?

   B. From home plate to the outfield wall of the nearest professional baseball stadium?

   C. From one wing tip of a Boeing 747 jumbo jet to the other?

   D. From one goal line to the other goal line on a football field?

3. Make a graph showing the distance from each person's marker to the actual 120-foot mark of the first flight. Did the group make good estimations of the distance? Find the average distance from the 120-foot mark.

4. Make a graph showing how long it took each person to run 120 feet. Did the group run faster than the Wright Flyer flew? Find the average time for the group.

Math challenge

1. Your car can easily go 60 miles per hour and a jet airliner can cruise at 600 miles per hour. If the Wright Brothers flew 120 feet in 12 seconds on their first flight, calculate their speed in miles per hour.

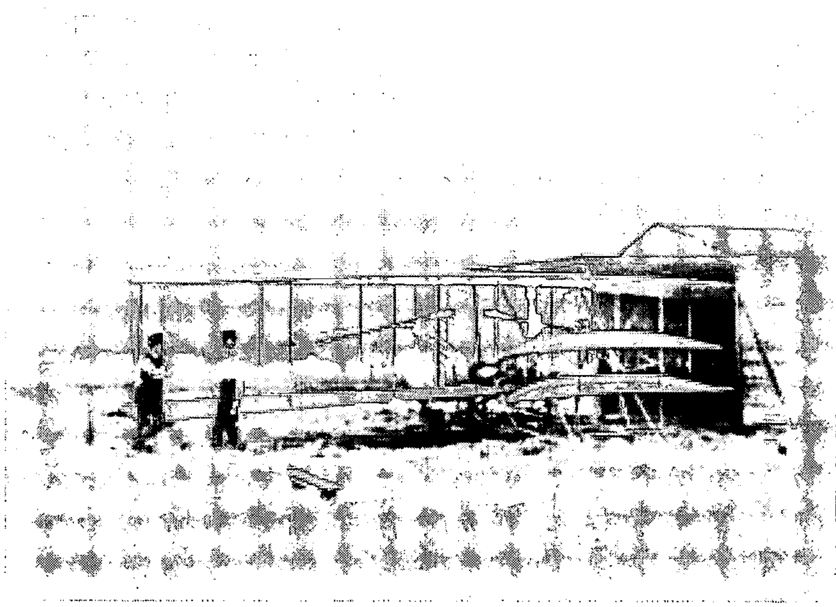
   Hint: To do this you need to change feet to miles by dividing 120 feet by 5280, the number of feet in 1 mile. Then you need to change 12 seconds to minutes by dividing by 60, the number of seconds in 1 minute, and then change minutes to hours by dividing your last answer by 60, the number of minutes in 1 hour. Now divide the number of miles by the number of hours to find speed in miles per hour.

1904: Improvements in Dayton

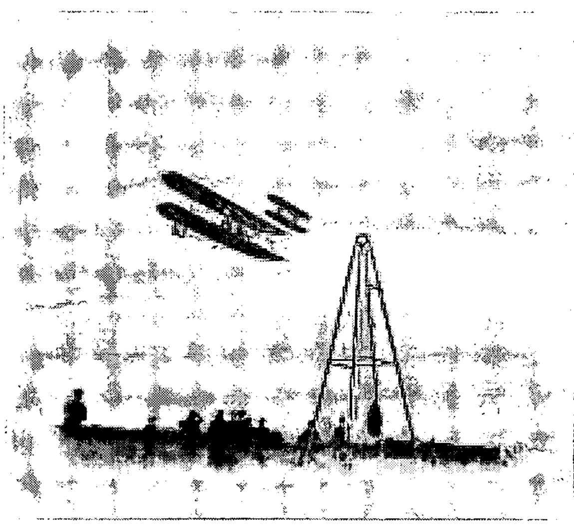
The Society now has you working on other projects, but you are still interested in the progress the Wright Brothers are making, so on your own, you travel up to Dayton in the fall of 1904. When you inquire at the shop, you are told that Wilbur and Orville are experimenting at a farm just outside Dayton owned by a man named Torrence Huffman. Before you go, you call on a friend who is a reporter for a Dayton newspaper. He tells you that the Wrights had twice invited the press out to see their invention, and both times, it didn't even fly! Nobody he knew was bothering to go back.

Puzzled by this, you catch the electric trolley and head for the Huffman farm. What you see amazes you. There, in a 100-acre cow pasture called "Huffman Prairie," you see Orville flying in a circle around the field! Wilbur is standing by a small building in the corner of the field, and you hurry over to greet him. He tells you that they had some bad luck with the engine both times they invited the press out, and now they don't come at all.

Astonished, you mumble something about how far the brothers have come since Kitty Hawk. Wilbur says that they've made a stronger frame with a larger engine, and moved the center of gravity to the rear, but have still not perfected the up-and-down control. It's hard to keep the craft from bobbing up and down. You ask how they get up into the air without the wind and hills at Kitty Hawk, and he shows you a launching derrick they built. A 1600-pound weight is hoisted to the top. When the weight drops, the plane is catapulted down 60 feet of track and becomes airborne. Their longest flight has been about 5 minutes.



Orville and Wilbur standing by the Wright 1904 Flyer.

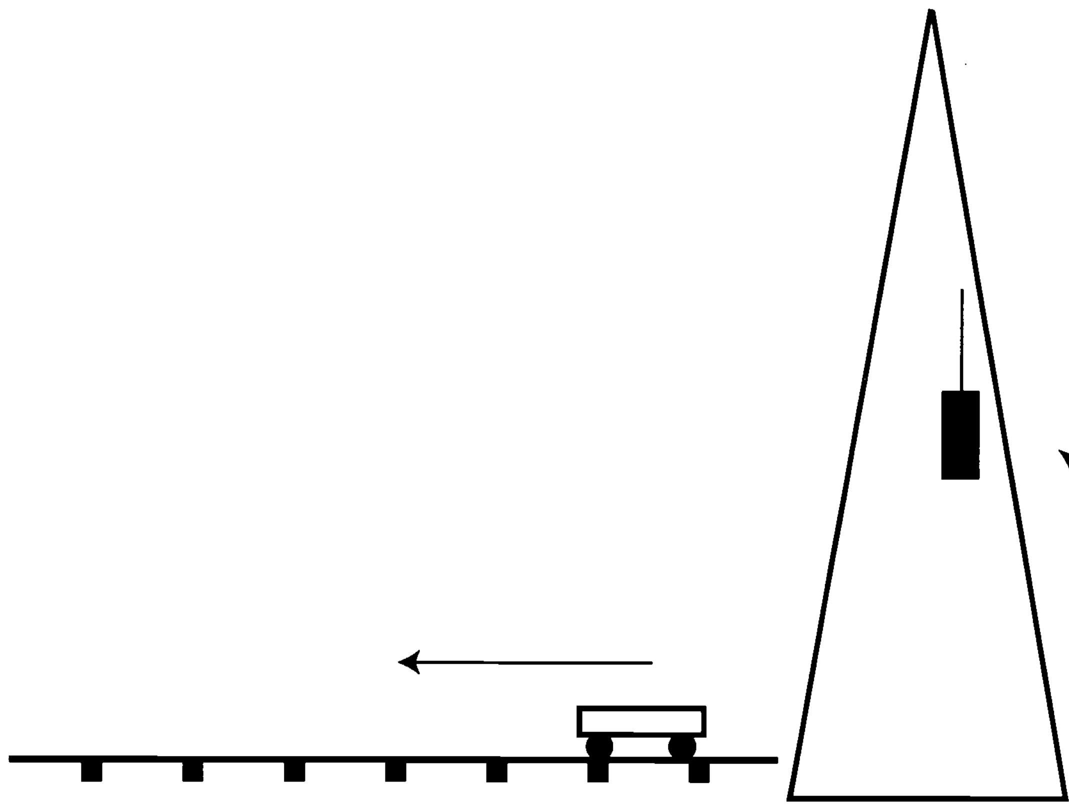


Launching derrick.

You stay and watch a few more flights, help the brothers put the flyer away, and ride back to Dayton with them on the trolley.

Activity 20–How To Launch the Flyer

This diagram represents the derrick (shown on page 34) used to launch the 1904 Flyer, which would rest on the small wheeled trolley (or launch cradle) shown on the launch track. The problem is how to get the launch cradle to move forward when the weight drops. Can you draw ropes (lines) and pulleys (circles) in a way that would make this happen? Draw arrows to show the direction each section of rope would move when the weight is dropped.



1. If the wind generally comes from the west, which way should the launch cradle travel?

2. What are the difficulties in using this launch system?

3. Why didn't they just use the force from the flyer's propellers to take off like planes do today?

Activity 21—Write a Press Release

Since the Wright Brothers got very little mention in the newspapers of the day, write an article about your observations of the accomplishments of the Wright Brothers that you can submit to the Dayton newspaper. Be sure that it is short and factual, just like a real news article.

Press Release

1905: Complete Flight at Last

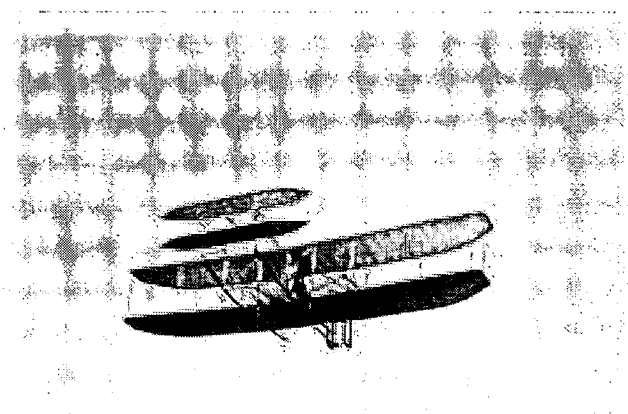
You hear from your Dayton friends that Orville and Wilbur have still not given up on perfecting flight. It is now 7 years since their kite experiments of 1899. After all the crashes, how easy it would have been for the brothers to quit long ago. You see a few items in the Cincinnati papers about their flights, but none of the New York or Chicago papers pick up these stories. The world still doesn't know much about their great achievements. You decide to visit again, and when you reach Huffman Prairie in October, you see that some major changes have occurred.

Flyer III sits on the rail ready to launch. The wings look the same, but the craft is a full 10 feet longer than the earlier model. The front elevator has been moved forward, and the rear rudders have been moved further to the rear. You watch as the weight drops in the launch derrick, the launch cradle carrying the flyer shoots down the track, and the flyer climbs into the air. Then, stunned, you watch as Orville circles the field again and again, does figure eights, and finally lands after 20 full minutes in the air! In addition, the flight looks smooth and totally controlled—no more jerky up-and-down motions as in 1903 and 1904.

"Wait until the Society hears about this!" you think excitedly. "It's just incredible. How can it be that the world still doesn't know about this? Is it that people don't understand it, or don't believe it?"

Wilbur explains calmly that they have achieved more precise control in flight by separating the controls for the rudder and wing-warping. Moving the front elevator and rear rudders away from the center of the plane also improves up-and-down control.

This 1905 airplane can be flown until the fuel tank is empty, staying in the air for more than half an hour at a time. It can fly for nearly 25 miles around Huffman's farm, executing turns and figure eights 50 feet above the ground. After 7 years of work, the brothers finally have a practical working airplane.

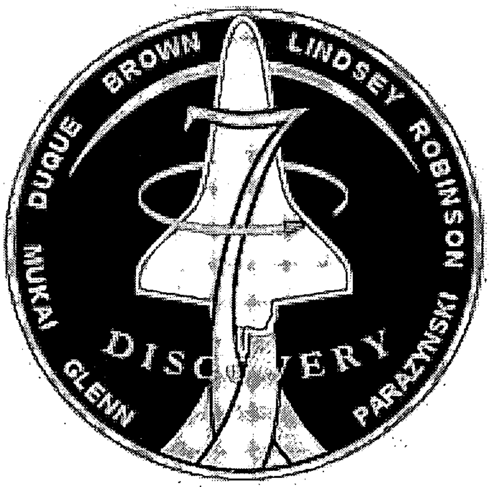


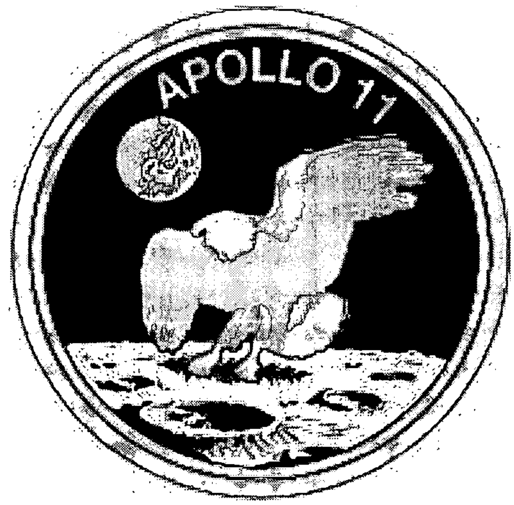
1905 Wright aircraft in flight.

As you leave, you thank Orville and Wilbur for letting you be a small part of their experiments, and you congratulate them, they've made the dream of powered flight come true. You feel privileged. After all that you've seen, you know that the world is on the verge of a big change.

Activity 22–Design a Mission Patch

A "mission patch," like the ones shown here, is designed for every NASA spaceflight. Choose one of the years from 1900 through 1905 and design a patch for the Wright Brothers' mission that year (you can find more mission patches under the "History" link at the top of the page at http://spaceflight.nasa.gov).

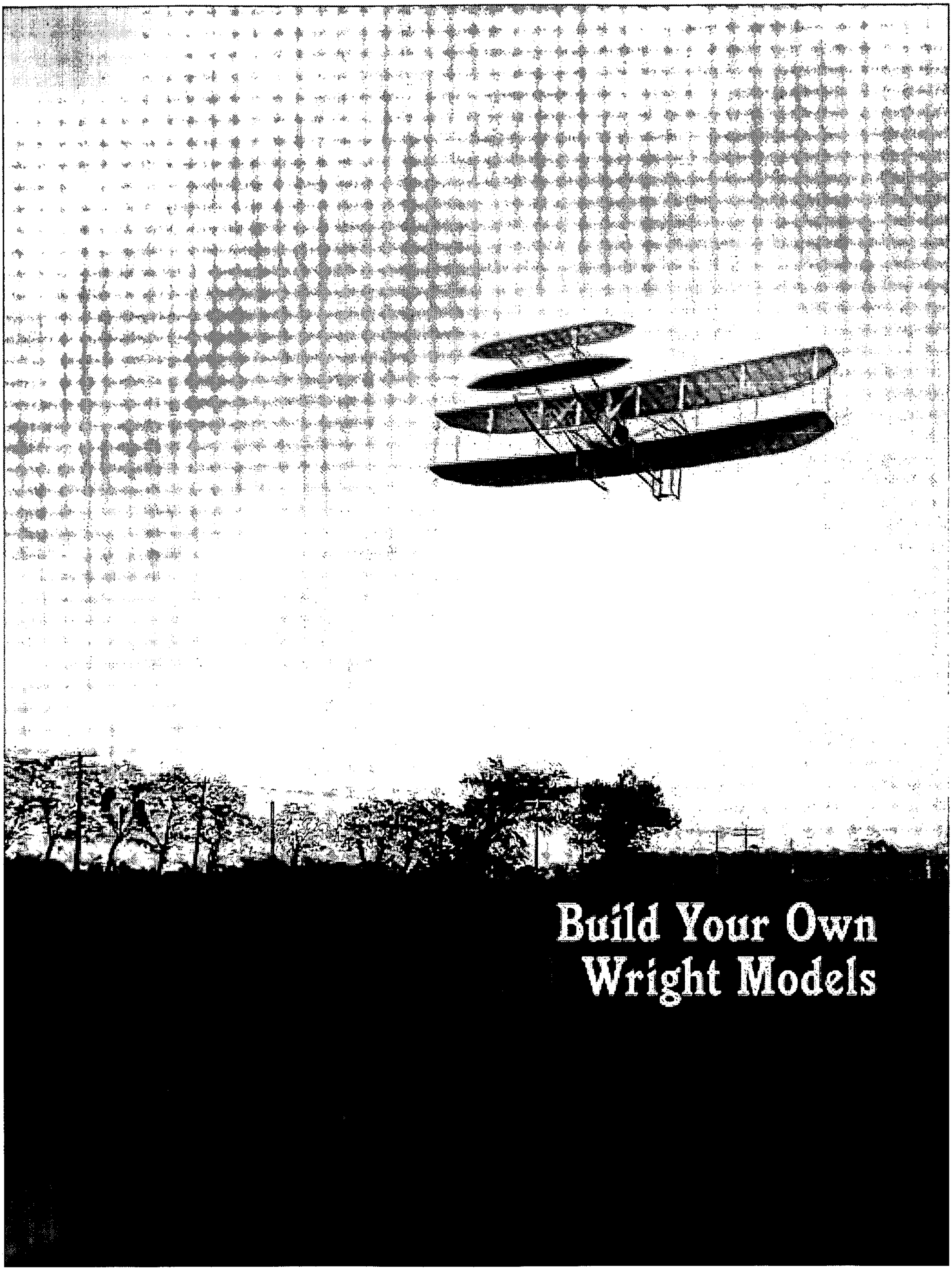




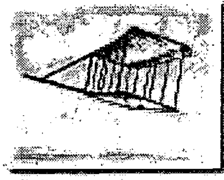
Activity 23–Be an Inventor

If you have read all the sections in this book about the Wright Brothers' quest for flight, you know that they followed a very logical process to solve a number of problems. Not everything they tried worked the first time, and they had to go back and redesign things several times to get them to work. In the end, their ideas were excellent; they are still used today to control a plane in three dimensions. They discovered how propellers work in the air and they constructed and used a wind tunnel to give accurate results. They were remarkable inventors.

Suppose you were an inventor and were also interested in transportation like Orville and Wilbur Wright. Write a short paragraph or two about what you would like to invent. How would your invention improve transportation? What problems do you think you would have to solve to be successful? How would you get people to learn about your invention? On another piece of paper, draw a diagram or sketch of your idea.



Build Your Own Wright Models



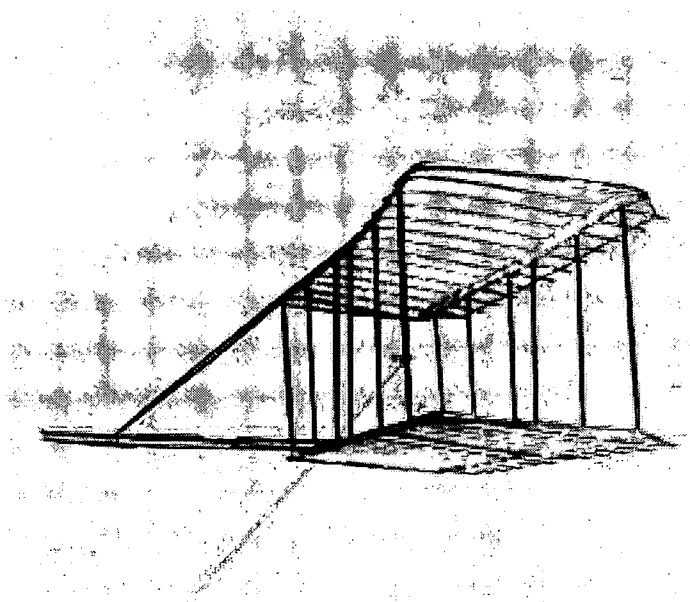
Wright Brothers 1900 Glider

The Wright Brothers' 1900 aircraft was flown repeatedly at Kitty Hawk, North Carolina, during the fall of 1900, mostly as a kite but also as a piloted glider.

The brothers' main concern at this time was to learn how to control the forces on an aircraft. Others who had thought it was more important to fly first and figure out control later had died in crashes. The Wright Brothers used this aircraft to learn the fundamentals of aerodynamics.

The brothers had observed soaring birds twist their wings to change direction and had successfully done the same thing, which they called "wing-warping," in 1899 by twisting the wings of a small kite. In 1900, the brothers decided to test wing-warping on an aircraft that was large enough to carry a person. The pilot could control the roll of the aircraft by using a foot pedal. The pedal was connected to wires that pulled on the wing tips and warped (or twisted) the wing, producing unequal forces on the wings, which would roll the aircraft.

The 1900 aircraft was relatively large: it had a 17-foot wingspan, a 5-foot chord, and 4 feet between the wings. Without the pilot, the 1900 craft weighed about 50 pounds. In 1900, glider pilots usually flew in a vertical position. The Wright Brothers correctly understood that this produced a lot of aerodynamic drag that would slow the glider down. They chose instead to streamline their aircraft by having the pilot lie horizontally on the lower wing. The aircraft had two wings covered by tightly woven sateen fabric, a stabilizer mounted on the front of the aircraft, and no tail.



All aircraft wings have a natural tendency to flip tail over nose because of the pressure distribution around the wing. To prevent their aircraft from flipping, the Wright Brothers attached a horizontal stabilizer (called a "canard," after the French word for "duck") to the front of the aircraft. On later models the shape of the stabilizer was varied by the pilot to provide pitch (up and down) control. But on the 1900 aircraft, they fixed the stabilizer in place and just tested the wing-warping. They found it too confusing at this time to prove both pitch and roll control.

For 3 weeks, the winds were so light that they flew their craft only as a kite, using chain to simulate the weight of a pilot and operating the controls by cable from the ground. On their final day the winds grew strong, so they decided to test the craft as a glider, with Wilbur as pilot. Launching from a dune hill, he made about a dozen glides, some lasting as much as 20 seconds and covering up to 400 feet, longer than a football field! Even though this was the only day of the season with winds strong enough to carry a pilot, the flights showed that wing-warping was a success. Lessons learned on the 1900 aircraft were incorporated into all of the later Wright aircraft.

Wright Brothers 1900 Glider Model Instructions

Designed by

Roger Storm, NASA Glenn Research Center

Materials

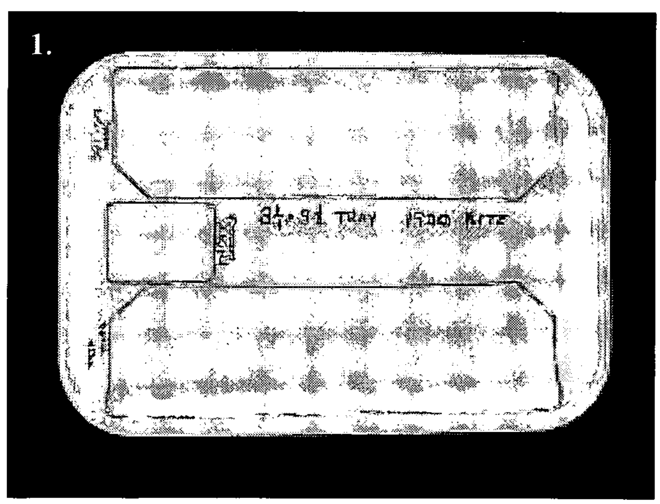
- One or two clean Styrofoam meat trays, at least 8.5 inches (21.5 centimeters) by 5.5 inches (14 centimeters), preferably white
- 30 to 35 toothpicks
- Low-temperature glue gun
- Scissors
- Hobby knife, razor utility knife, or single-edge razor blade (adult help here)
- Cardboard or board to cut on
- Ultrafine-tip black marker
- Ruler
- Emery board
- Manila file folder
- Small plastic toy army soldiers, about 2 inches (5 centimeters) tall (optional)

General Instructions

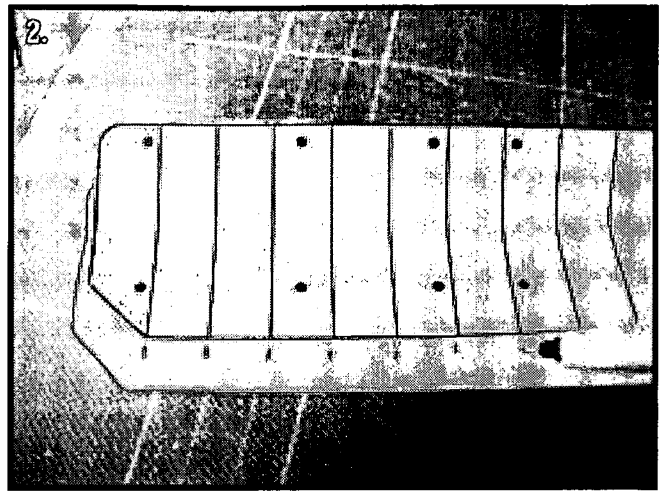
- Use scissors to cut out all three templates on the heavy lines of the 1900 Glider template (found in the back of this book).
- Do all hobby knife or razor blade cutting on the board or cardboard to protect your working surface.
- The finished model is for display only; it is not meant to fly.

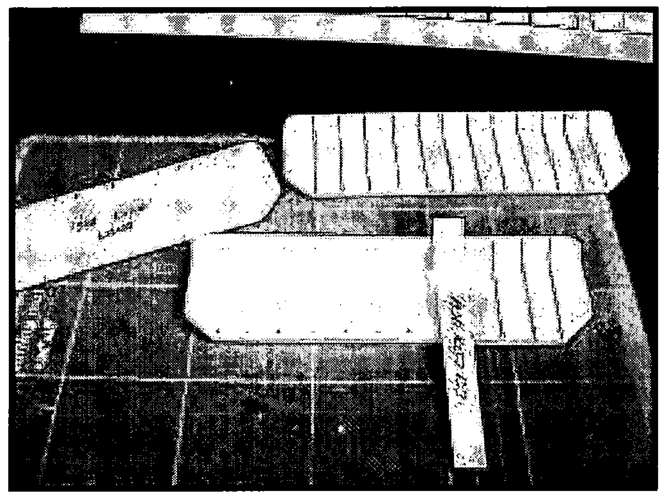
Procedure

1. Carefully trace the wing and elevator shapes on the inside of the Styrofoam tray as shown. Be sure the front edges of the wings go about two-thirds of the way up the curved sides of the tray. Check the bottom of the tray and avoid any logo found there. You may need two trays. Cut out the wings and elevator with the hobby knife or scissors. Use the emery board to smooth the cut edges and sand off the pen lines.

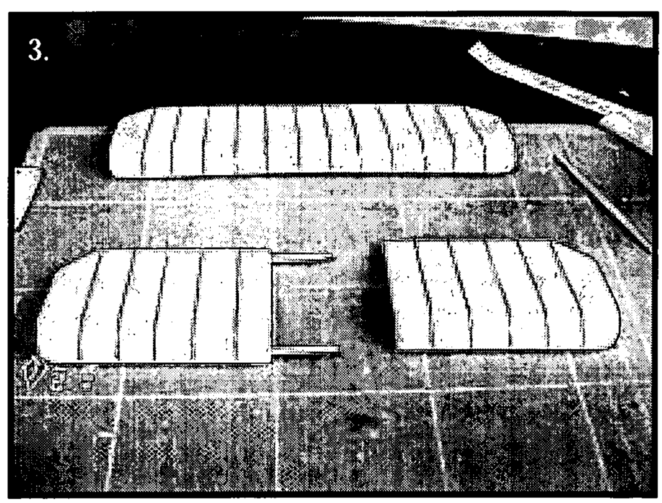


2. Using the templates as a guide, mark the locations of the rib lines on the tops and bottoms of the wing and elevator sections with the ultrafine-tip black marker. Make two sets of marks, one on each edge. Connect the marks to make the rib lines. Make a rib template from a manila folder to draw the rib lines (so the end of the template can be bent to conform to the rounded shape of the Styrofoam).

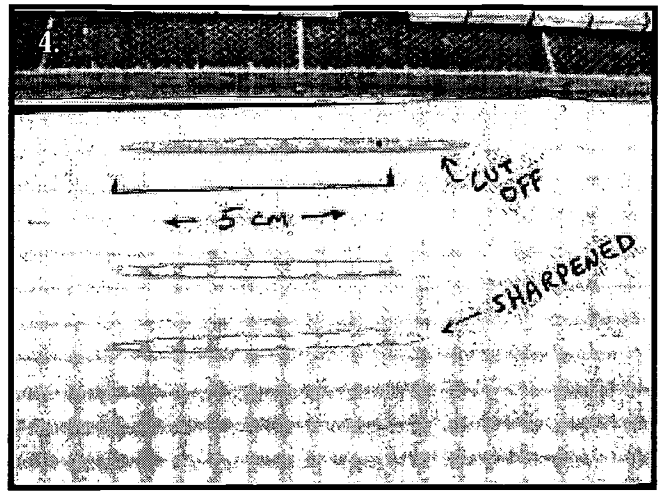




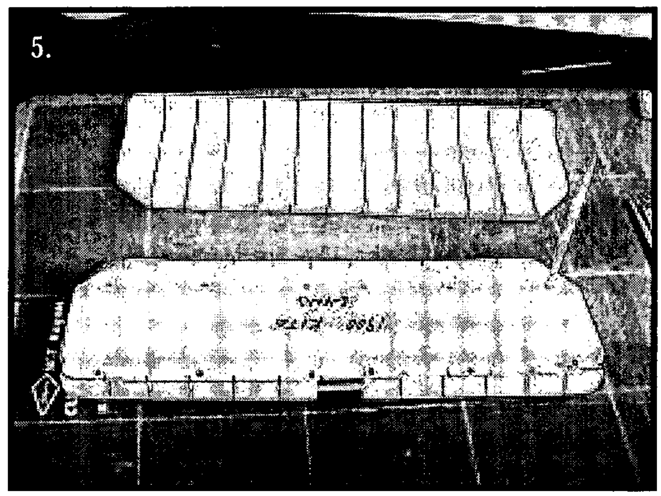
3. Cut out the center of the lower wing only as shown by the dotted lines on that template. Cut a toothpick in half and sharpen the cut ends. Dip the ends in glue and stick them in the cut edges to join the lower wing halves, leaving a .6-inch (1.5-centimeter) gap between the halves. (If the Styrofoam is thin, glue the toothpicks to the underside of the wing instead.)



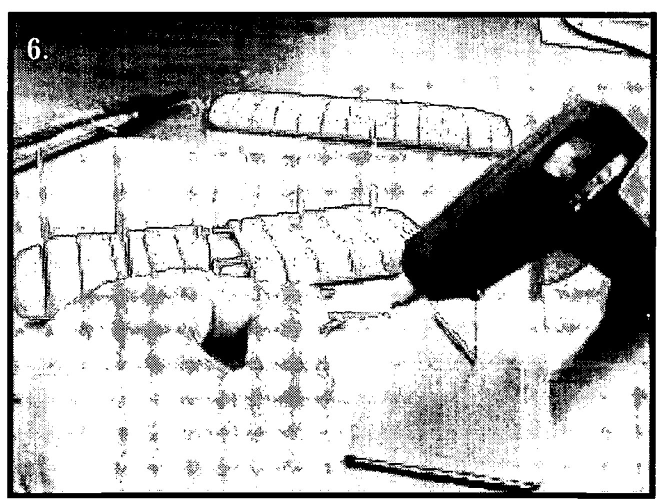
4. Make 12 spars by cutting toothpicks to a 2-inch (5-centimeter) length and sharpening the cut ends.



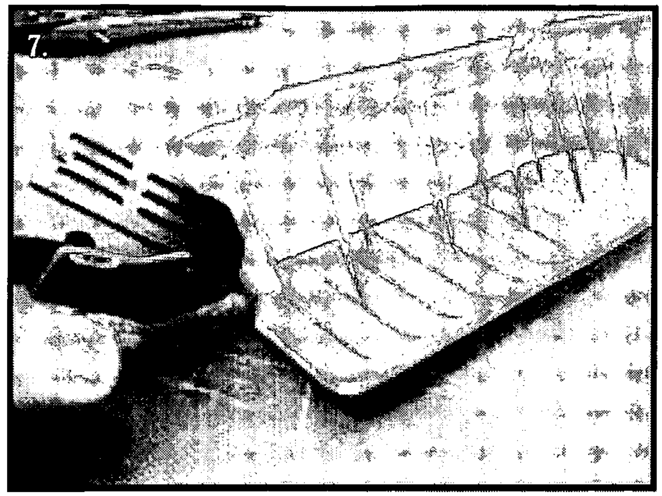
5. Use the wing template and a sharp toothpick to mark the holes for the spars on the top surface of the lower wing and bottom surface of the upper wing. Note that the front edges of the wings curve down. In this picture the upper wing in the back is upside down.



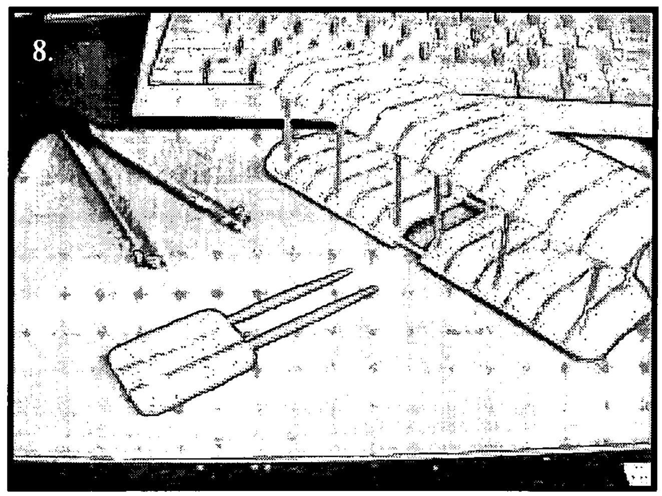
6. Dip toothpicks in glue and insert them in the spar holes now marked in the lower wing. Try not to push them all the way through the wing. Be sure they are standing up as straight as possible.



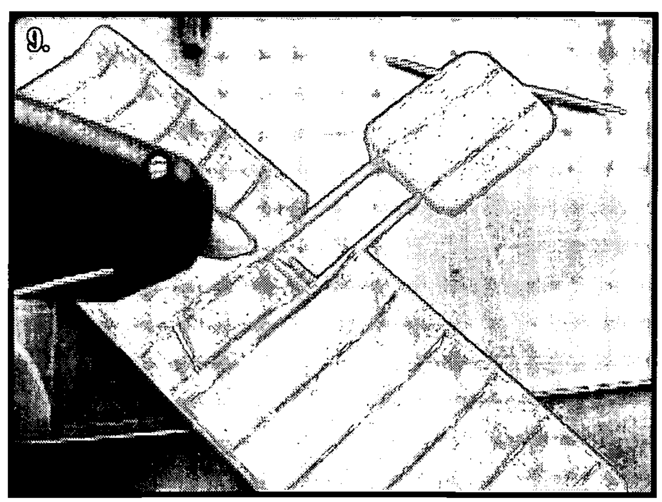
7. Now, with both the upper and lower wings and wings upside down (the edges should be curving up at this point), insert the back row of spars into the underside of the top wing. Use the marked holes as a general guide, but keep the spars straight and evenly spaced. Put a little glue on each to keep them in place as shown in the picture. Now join the front spars to the top wing, remembering to keep them straight and fasten them with dabs of glue. This takes some effort to get everything in the right place and is easier to do with two people.



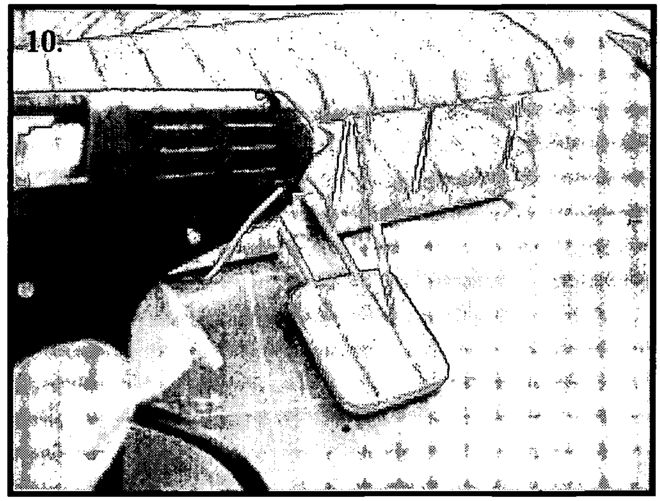
8. Stick two toothpicks into the edge of the end of the elevator and add a dab of glue to hold them in place. (If the Styrofoam is thin, glue toothpicks to the underside of the elevator instead.)



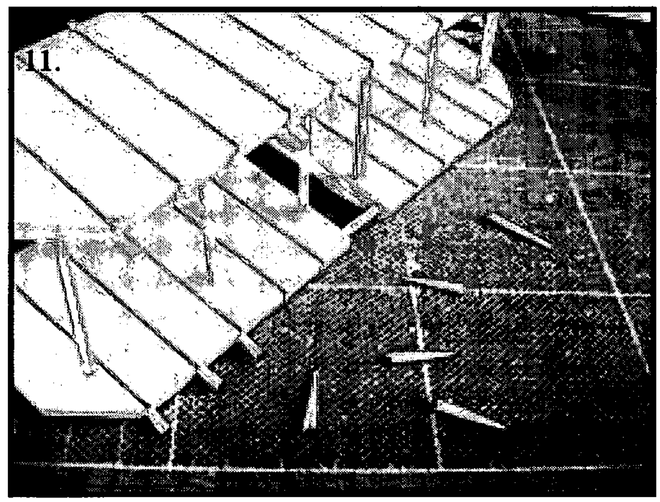
9. Turn the glider over and glue the elevator assembly on either side of the opening in the lower wing as shown.



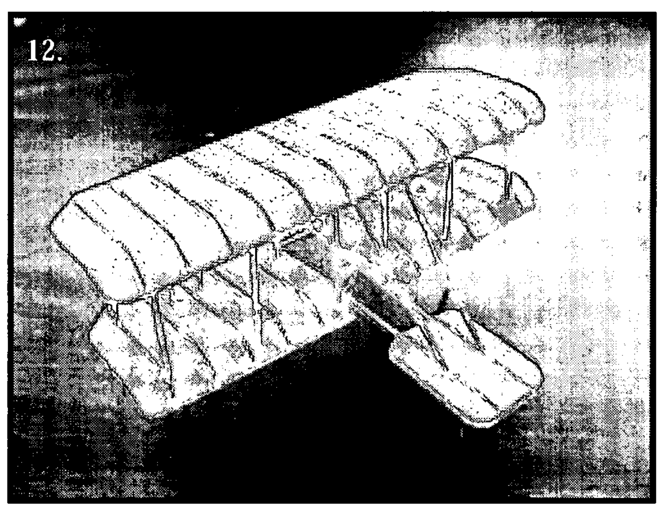
10. Turn the glider over again and insert a toothpick in the center of the left rib line as shown and add a bit of glue. Then insert the other end of the toothpick into the front edge of the upper wing and glue. Add another toothpick in the same way to the right rib line. (If the Styrofoam is thin, glue these to the underside of the upper wing instead.)

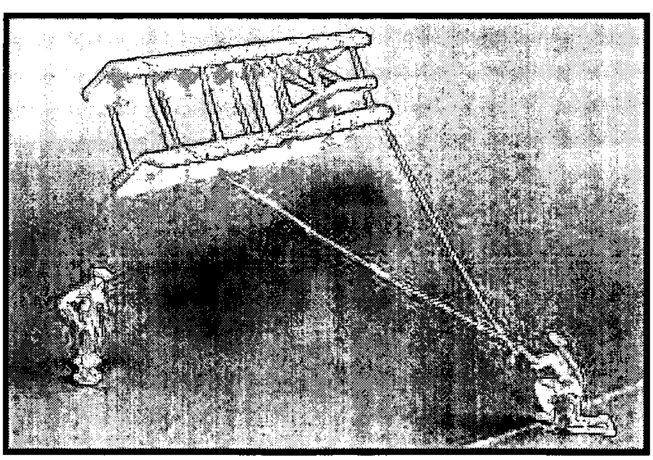


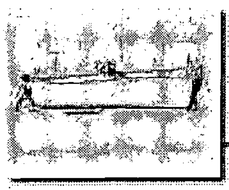
11. (Optional) Cut enough .6-inch (1.5-centimeter) toothpick pieces to stick into the back edge of each wing on the lines to simulate the ribs.



12. For display, the kite can be hung on a thread and strings can be added to be held by kneeling plastic toy soldiers. ADULTS: You may add figures by cutting, swapping, and gluing parts of plastic army soldiers. To obtain the desired poses, arms and legs can be removed and some from other soldiers glued in their place. Guns and helmets should be trimmed away using a hobby knife and the figure arms and legs can be shaped, swapped, or repositioned to fit and glued on. Five-minute epoxy works best for this. See steps 12 of the 1901 Glider instructions (pages 52 and 53) for more detailed illustrations.





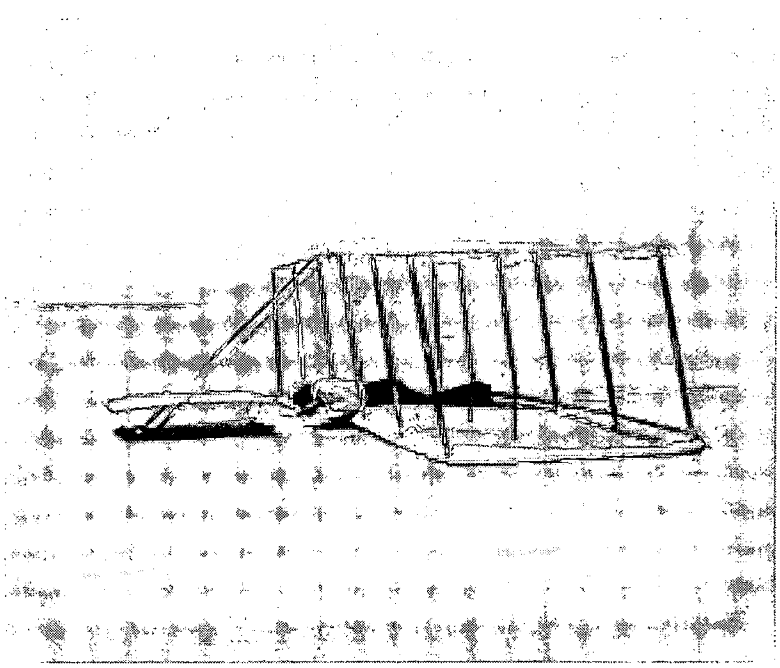


Wright Brothers 1901 Glider

The 1901 Glider was the second unpowered aircraft built by the brothers. The aircraft was flown repeatedly at Kitty Hawk during 1901 as a piloted glider and as a kite. The Wright Brothers learned more about the fundamentals of aerodynamics using this aircraft, which they began building in 1900.

The 1901 aircraft was larger than the 1900 aircraft, but of the same basic design: it had two wings, no tail, and an elevator-stabilizer mounted in the front of the aircraft. The wingspan was increased from 17.5 to 22 feet, and the chord (front edge of the wing to the back edge) was changed from 5 to 7 feet, increasing the overall wing area from 165 to 290 square feet. The brothers wanted to provide more lift so they could pilot their glider in winds of less velocity. Without the pilot, the 1901 craft weighed about 100 pounds. The pilot would lie on the bottom wing and control the roll of the aircraft with a foot pedal. The pedal was connected to wires that pulled on the wing tips and warped (or twisted) the wing, producing unequal forces on the wings, which would roll the aircraft. On the 1901 aircraft, the pilot could also change the shape of the elevator to control the up or down position of the nose, or pitch, of the aircraft.

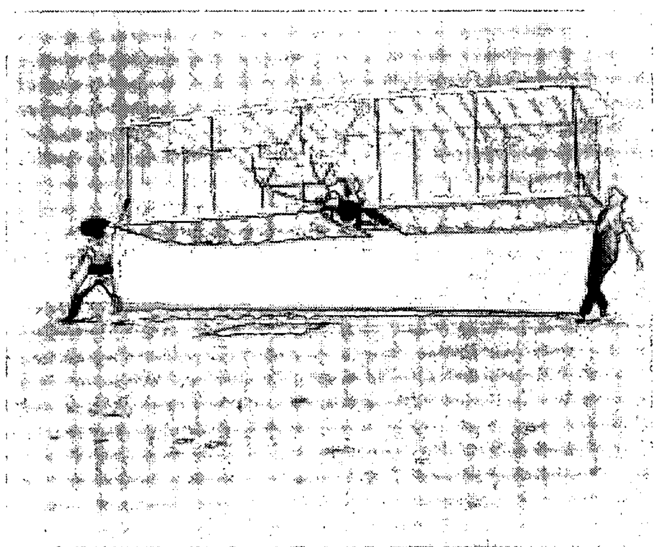
The aircraft was flown frequently up to 300 feet in a single glide, but did not perform as well as the brothers had expected. To improve the flying characteristics, they installed additional struts (structural pieces added to provide support and designed to resist pressure in the direction of their lengths) on the lower wing to alter the camber (or curve) of the aircraft wing. The photo to the right shows the aircraft immediately after landing, and you can see the additional struts between the wings at the center.

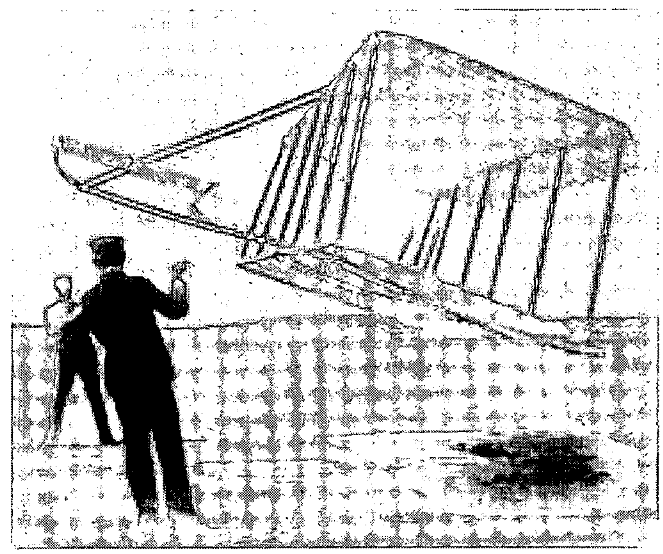


Wilbur Wright testing his flying position in the 1901 Glider.

During their test flights the brothers encountered an effect known as "adverse yaw." Sometimes when the wings were warped to produce roll, which should have resulted in a curving flight toward the lower wing, the increased drag on the upper wing twisting in the opposite direction caused the air speed to decrease, and the aircraft would turn into the ground.

While trying to solve these new problems, the Wrights gathered the first real usable and accurate aerodynamic data obtained by experimenting with a wind tunnel. These results would be applied to the 1902 aircraft, which would answer many questions raised by the 1901 aircraft (shown in the photos below) as the brothers progressed toward the successful 1903 Flyer.



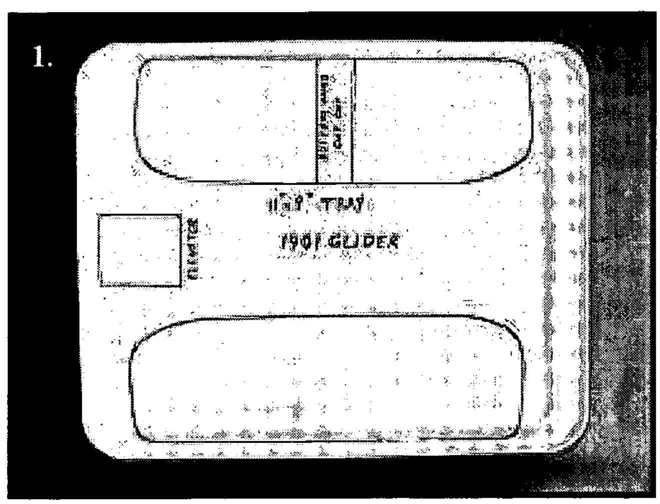


Designed by
Roger Storm, NASA Glenn Research Center

Materials
- One or two clean Styrofoam meat trays, at least 9 inches (23 centimeters) by 11 inches (28 centimeters), preferably white
- 30 to 35 toothpicks
- Low-temperature glue gun
- Scissors
- Hobby knife, razor utility knife, or single-edge razor blade (adult help here)
- Cardboard or board to cut on
- Ultrafine-tip black marker
- Ruler
- Emery board
- Manila file folder
- Small plastic toy army soldiers, about 2 inches (5 centimeters) tall (optional)

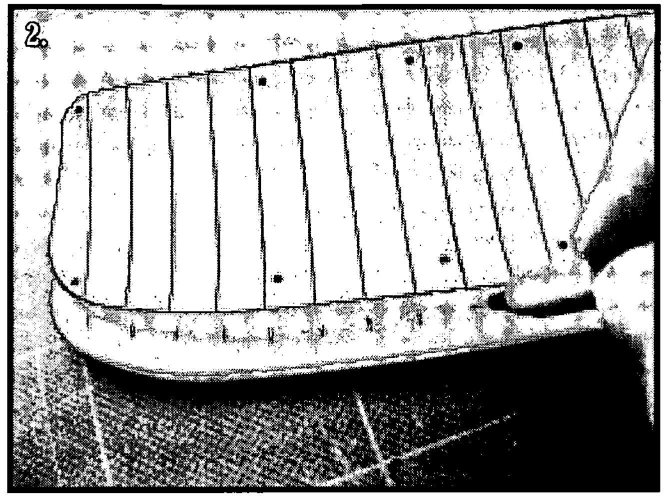
General Instructions
- Use scissors to cut out all three templates on the heavy lines of the 1901 Glider template (found in the back of this book).
- Do all razor knife or razor blade cutting on the board or cardboard to protect your working surface.
- The finished model is for display only; it is not meant to fly.

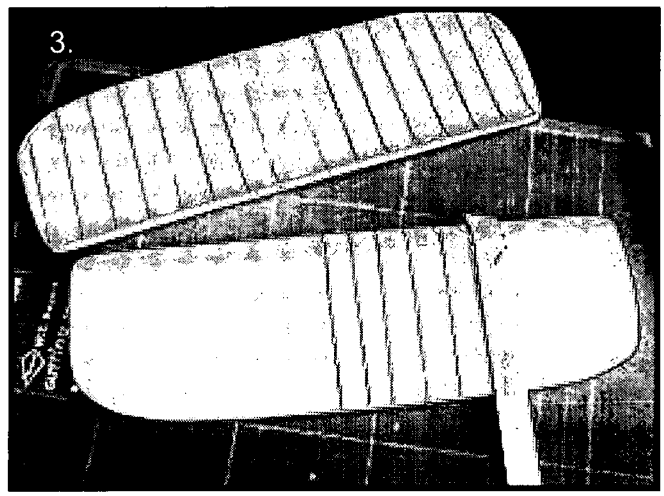
Procedure
1. Carefully trace the wing and elevator shapes on the inside of the Styrofoam tray as shown. Be sure the front edges of the wings go about two-thirds of the way up the curved sides of the tray. Check the bottom of the tray and avoid any logo found there. You may need two trays. Cut out the wings and elevator with the hobby knife or scissors. Use the emery board to smooth the cut edges and sand off the pen lines.



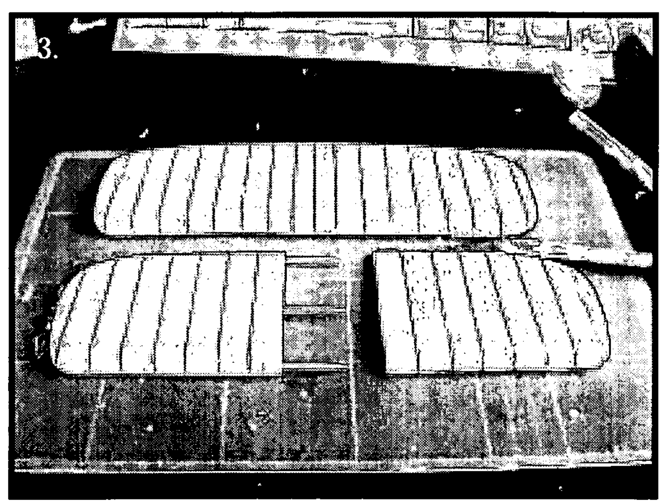
1.

2. Using the templates as a guide, mark the locations of the rib lines on the tops and bottoms of the wing and elevator sections with the ultrafine-tip black marker. Make two sets of marks, one on each edge. Connect the marks to make the rib lines. Make a rib template from a manila folder to draw the rib lines (so the end of the template can be bent to conform to the rounded shape of the Styrofoam).

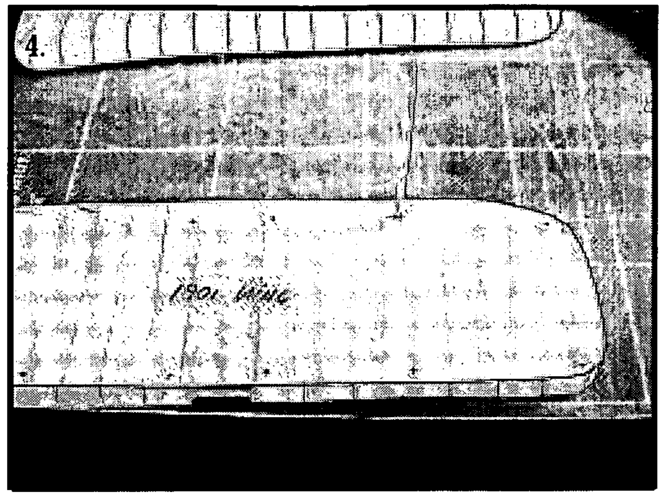




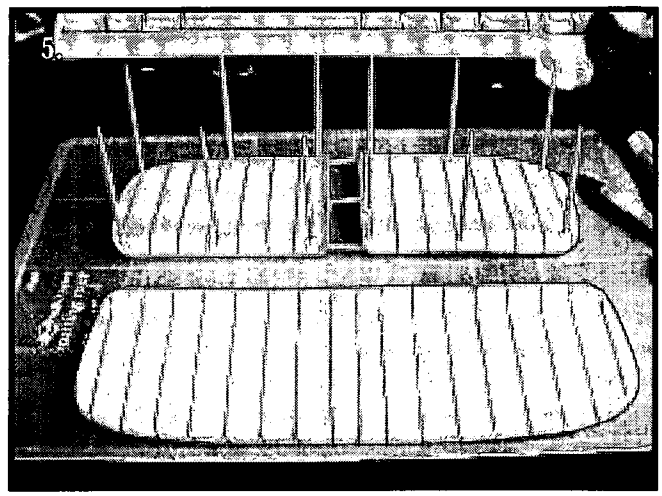
3. Cut out the center of the lower wing (only of the lower wing) as shown by the dotted lines on the template. Cut two toothpicks in half and sharpen the cut ends of three of them. Dip the ends in glue and stick them in the cut edges to join the lower wing halves, leaving a .6-inch (1.5-centimeter) gap between the halves. (If the Styrofoam is thin, glue the toothpicks to the underside of the wing instead.)



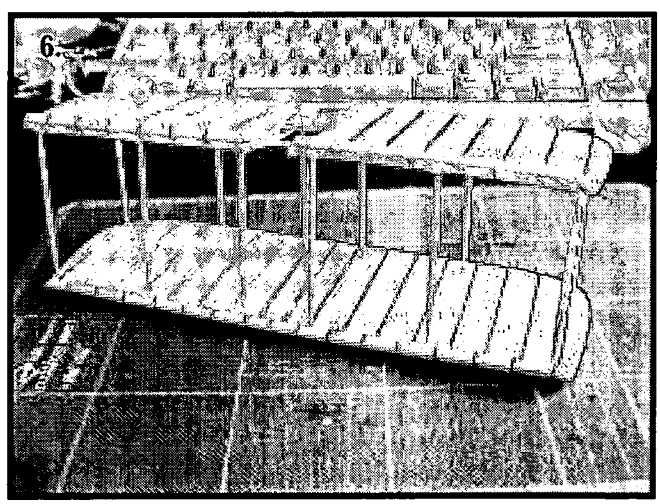
4. Use the wing template and a sharp toothpick to mark the holes for the spars on the top surface of the lower wing and the bottom surface of the upper wing. Note that the front edges of the wings curve down. In this picture the upper wing in the background needs to be turned upside down.



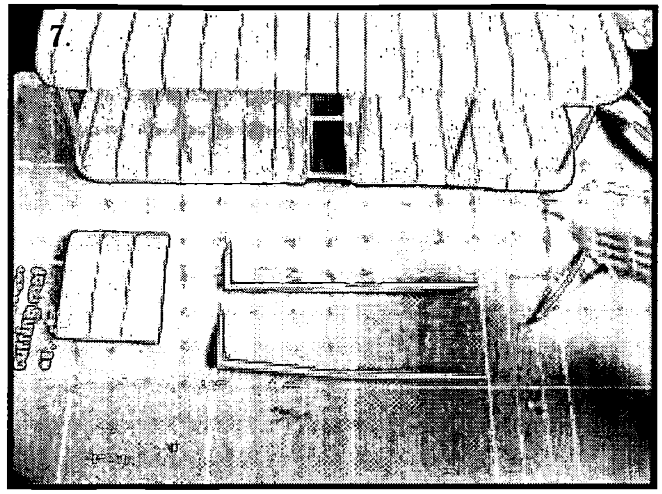
5. Dip toothpicks in glue and insert them in the spar holes now marked in the lower wing. Try not to push them all the way through the wing. Be sure they are standing up as straight as possible. The upper wing in the foreground of this picture is upside down (the curved edge is curving up).



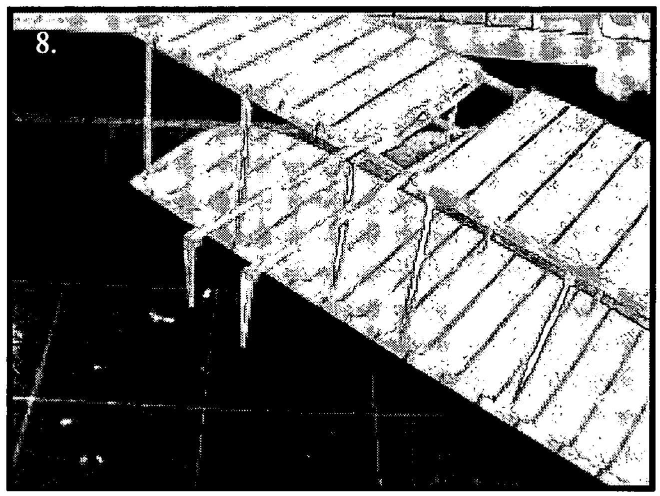
6. Now, with both the upper and lower wings upside down (the edges should be curving up at this point), insert the back row of spars into the underside of the top wing. Use the marked holes as a general guide, but keep the spars straight and evenly spaced. Put a little glue on each to keep them in place as shown in the picture. Now join the front spars to the top wing, remembering to keep them straight, and fasten them with dabs of glue. This takes some effort to get everything in the right place and is easier to do with two people.



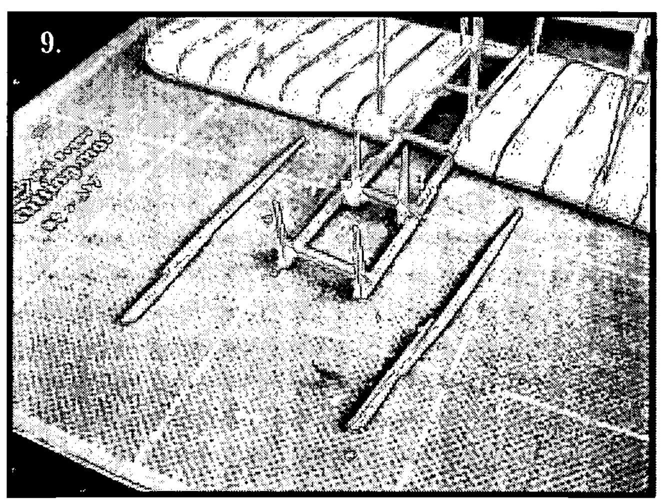
7. To make a skid, join two toothpicks end to end and side by side so the overall length is 4.3 inches (11 centimeters). When the glue is dry, cut them to a length of 3.5 inches (9 centimeters) and then glue the cutoff end back on at a 90-degree angle as shown. Repeat the process for the second skid.



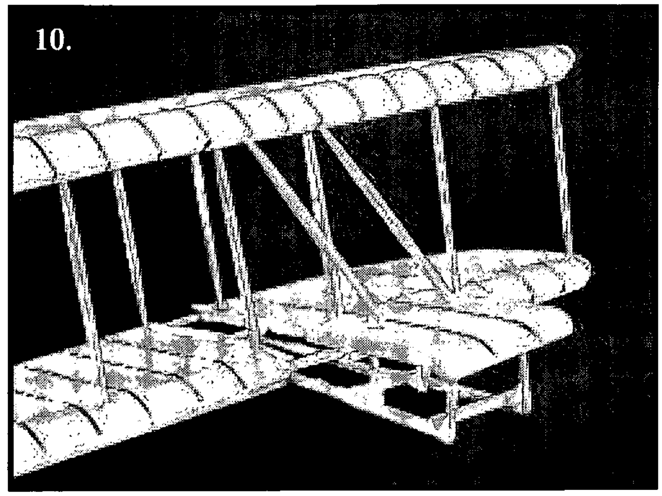
8. Turn the wing assembly upside down and glue the skids on either side of the opening in the lower wing. The skids should overlap the front and middle toothpicks that join the wing halves and should extend out beyond the front (curved edge) of the lower wing.



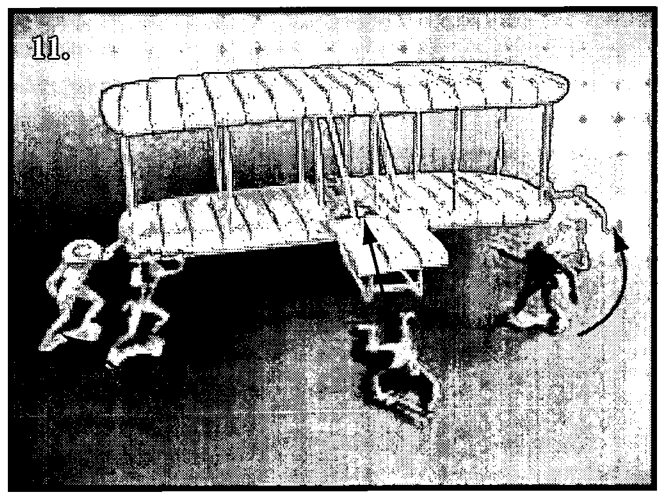
9. Turn the assembly back over so it is right side up, and cut two pieces of the right length to brace between the two skids. Glue one at the end and one at the middle. Cut two more pieces for upright support for the elevator and glue them sticking up at the middle cross brace. Make two braces to go from the upper wing to the elevator by joining two toothpicks end-to-end and trimming them to a length of 2.5 inches (6.5 centimeters).



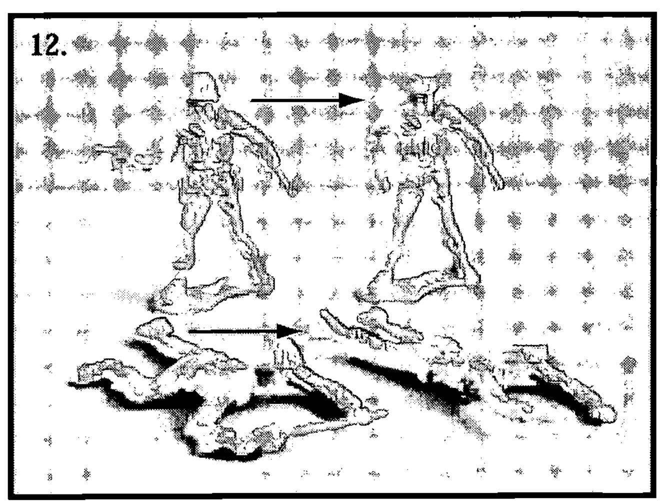
10. Place glue on the ends of the four upright supports and push them into the elevator. Also put glue on both ends of the upper braces and push them first into the center of the top of the elevator along the rib lines, and then into the front edge of the upper wing, as shown. (If the Styrofoam is thin, glue the braces to the underside of the upper wing instead.)

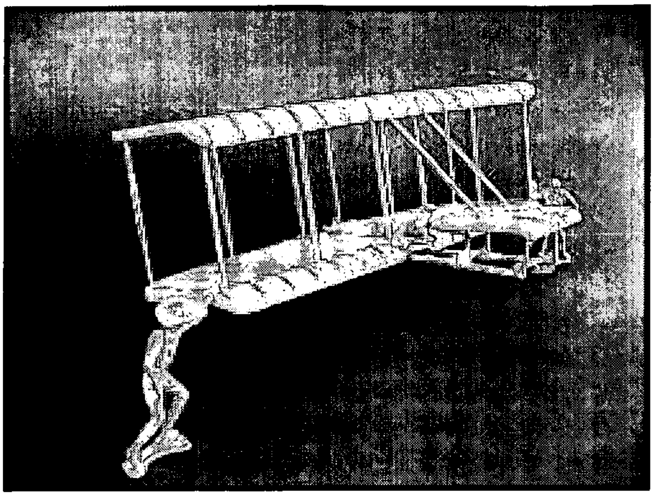


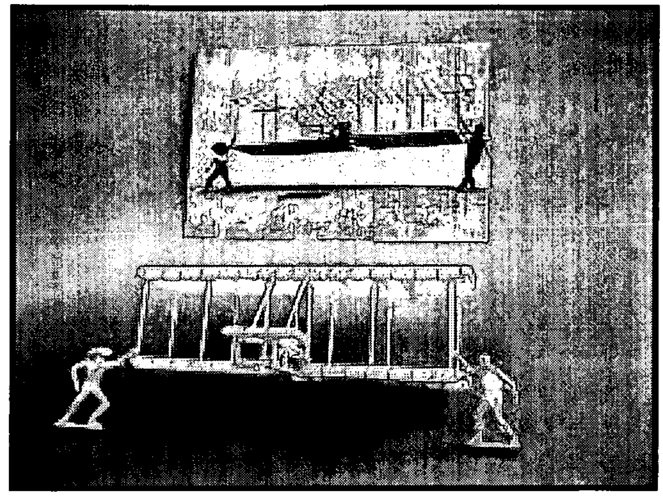
11. (Optional) You can make the figures of Wilbur and Orville Wright by swapping and gluing parts of plastic army soldiers. To obtain the desired poses, arms and legs can be removed and some from other soldiers glued in their place. Guns and helmets should be trimmed away using a hobby knife and the figure arms and legs can be shaped, swapped, or repositioned to fit and glued on. Five-minute epoxy works best for this. The dark soldiers in the photograph are the original shapes and the light soldiers are the final shapes.

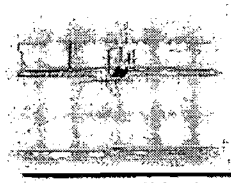


12. The original soldiers on the left were transformed into the figures of Wilbur and Orville Wright on the right.









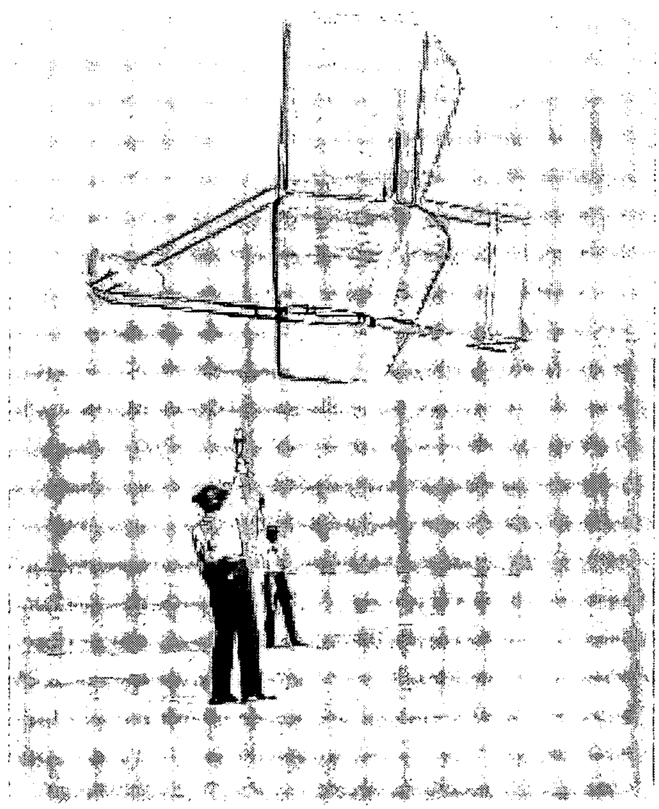
Wright Brothers 1902 Glider

The Wright Brothers' 1902 Glider was their third unpowered aircraft. It was flown repeatedly at Kitty Hawk during 1902 as a kite and as a piloted glider. The brothers used this aircraft to solve some of the problems encountered with the 1901 Glider. They also used it to develop their piloting skills, because this was the first aircraft in the world that had active controls for all three axes: roll, pitch, and yaw.

The 1902 aircraft had two wings and an elevator-stabilizer mounted in the front, like the 1901 aircraft. It had a 32-foot wingspan, a 5-foot chord, and 5 feet between the wings. Without the pilot, it weighed about 120 pounds. As before, the pilot lies on the bottom wing and controls the roll of the aircraft by warping the wing shape. On the 1902 aircraft, however, and on all flyers through 1905, the warping was controlled by a control device called a "hip cradle," instead of the pedals that were used on the 1900 and 1901 aircraft.

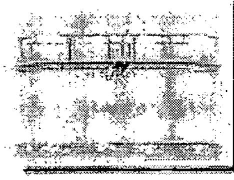
There were other major differences between this aircraft and its predecessors as well. Data from the 1901 wind tunnel experiments showed that a longer, thinner wing gave less drag and a better lift-to-drag (L/D) ratio, so the aspect ratio (ratio of wingspan to wing chord or width) was changed from 3:1 on the 1901 aircraft to 6:1 on the 1902 aircraft. To try to solve the problem of adverse yaw from the 1901 Glider, two 6-foot rudders were added to the rear of the craft.

Test flights went better than in 1901, but occasionally, the glider would spin out of control on recovering from a turn at low speed. Lying awake one night, Orville concluded that the rudder was acting like a vertical wing, in which turning generated an angle of attack, and thus, an unwanted force in the wrong direction. To correct this, a single, movable rudder was attached at the rear and connected to the wing-warping.



Now perfected, the glider worked beautifully, keeping the nose of the aircraft pointed into the curved flight path. On the 1902 aircraft, the pilot could also change the angle of the elevator to control the up and down position, or pitch, of the nose of the aircraft. For the first time in history, a craft could be controlled in three dimensions. With this new aircraft, the brothers completed gliding flights of over 650 feet.

At the end of 1902, all that remained for the first successful airplane was the development of the propulsion system. During the following winter and spring, the brothers built their own small engine from scratch and perfected their own propeller design for the 1903 flyer.



Wright Brothers 1902 Glider Model Instructions

Designed by

Roger Storm, NASA Glenn Research Center

Materials

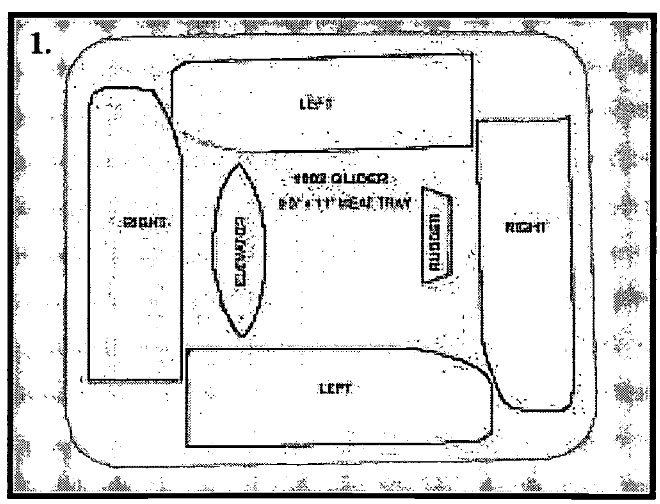
- One or two clean Styrofoam meat trays, at least 9 inches (23 centimeters) by 11 inches (28 centimeters), preferably white
- 30 to 35 toothpicks
- Low-temperature glue gun
- Scissors
- Hobby knife, razor utility knife, or single-edge razor blade (adult help here)
- Cardboard or board to cut on
- Ultrafine-tip black marker
- Ruler
- Emery board
- Manila file folder
- Small plastic toy army soldiers, about 2 inches (5 centimeters) tall (optional)

General Instructions

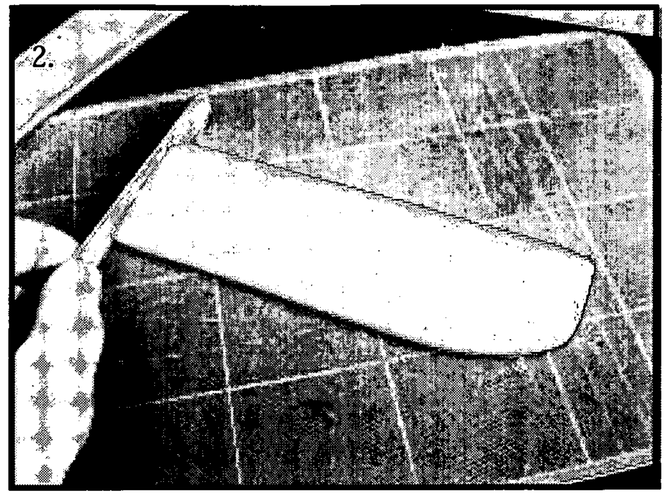
- Use scissors to cut out all three templates on the heavy lines of the 1902 Glider template (found in the back of this book).
- Do all hobby knife or razor blade cutting on the board or cardboard to protect your working surface.
- The finished model is for display only; it is not meant to fly.

Procedure

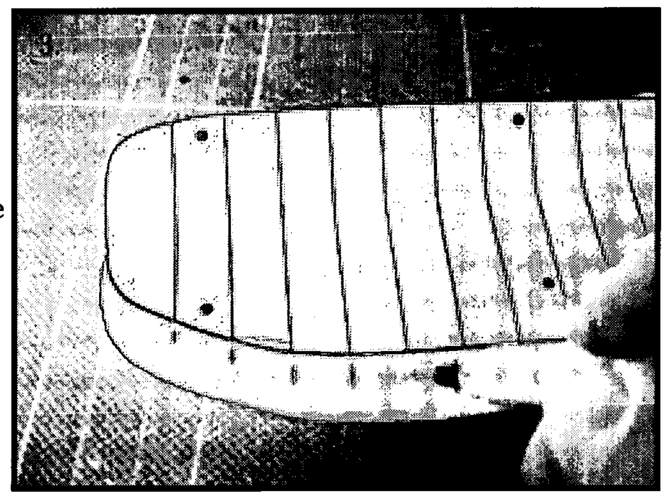
1. Carefully trace the wing and elevator shapes on the inside of the Styrofoam tray as shown. Be sure the front edges of the wings go about two-thirds of the way up the curved sides of the tray. Check the bottom of the tray and avoid any logo found there. You may need two trays. Cut out the wings and elevator with the hobby knife or scissors.

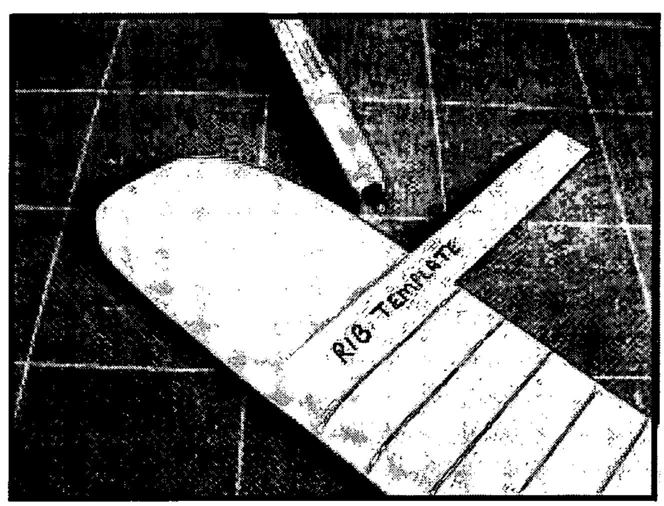


2. Use the emery board to smooth the edges and sand off the pen lines. Make sure that the two halves of the upper wing are flat where they will be joined, as shown at the right.

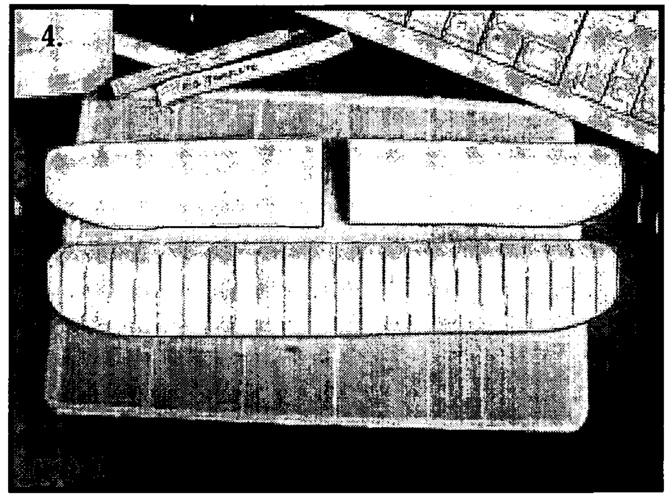


3. Using the templates as a guide, mark the locations of the rib lines on the tops and bottoms of the wing and elevator sections with the ultrafine-tip black marker. Make two sets of marks, one on each edge. Connect the marks to make the rib lines. Make a rib template from a manila folder to draw the rib lines (so the end of the template can be bent to conform to the rounded shape of the Styrofoam).

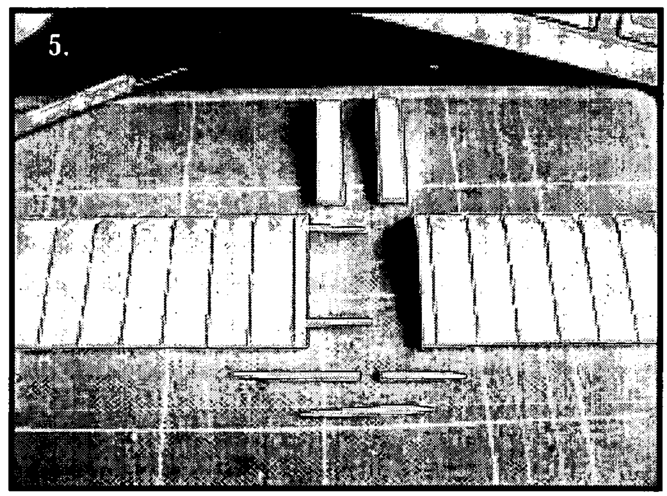




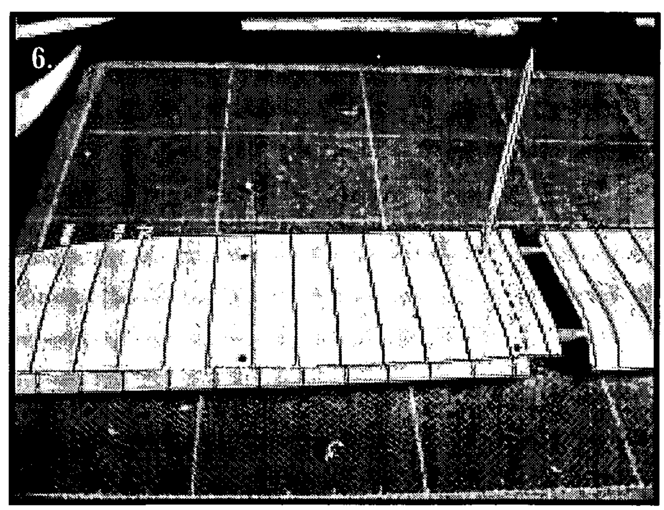
4. Place glue on the flat edge of the upper wing halves and join them as shown.



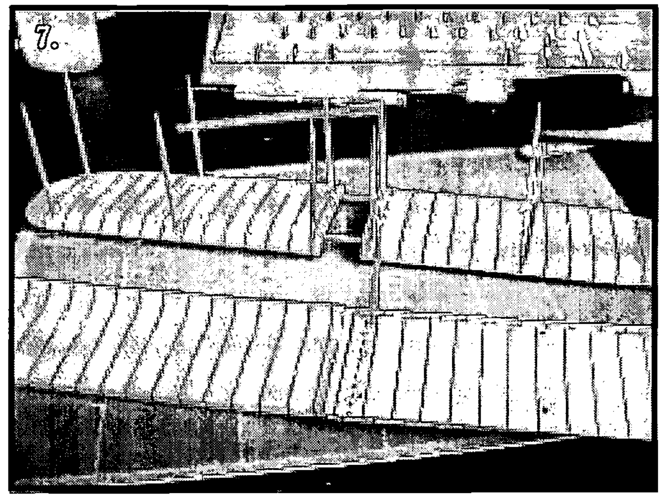
5. Cut off the parts of the lower left and right wing only as shown by the dotted line on the template. Cut a toothpick in half and sharpen the cut ends. Dip the ends in glue and stick them in the cut edges to join the lower wing halves, leaving a .6-inch (1.5-centimeter) gap between the halves. (If the Styrofoam is thin, glue the toothpicks to the underside of the wing instead.)



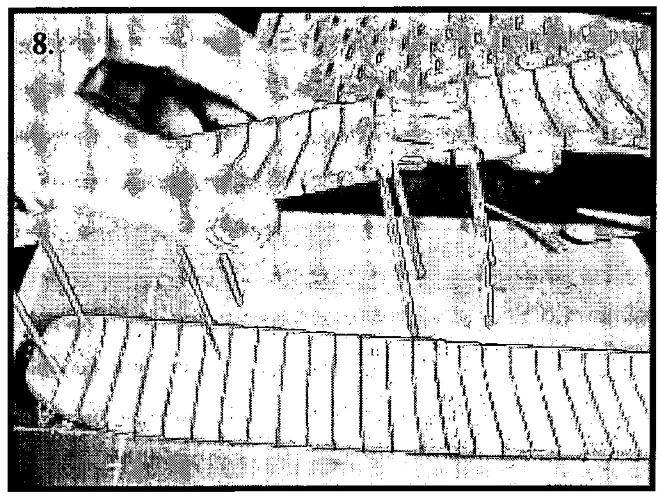
6. Use the wing template and a sharp toothpick to mark the holes for the spars on the top surface of the lower wing (the front edge should curve down as shown) and the bottom surface of the upper wing.



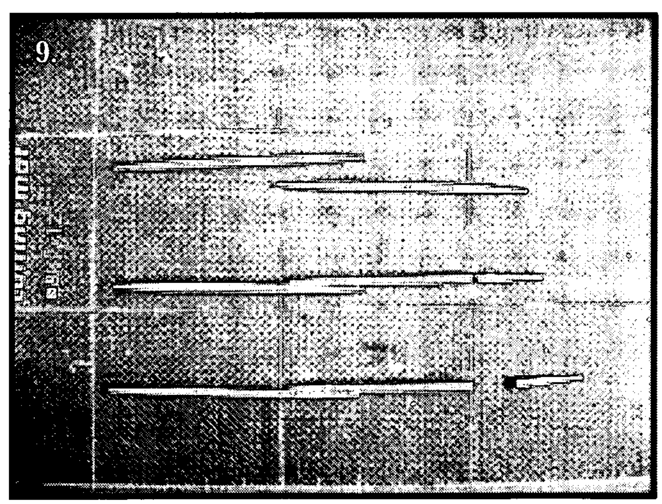
7. Dip toothpicks in glue and insert them in the spar holes now marked in the lower wing. Try not to push them all the way through the wing. Be sure they are standing up as straight as possible.



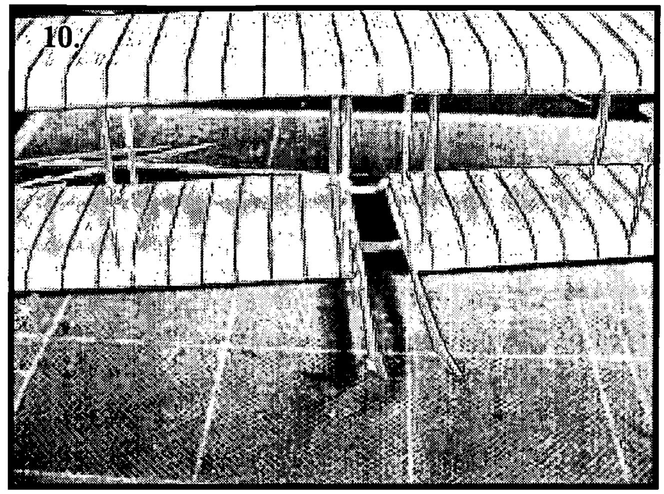
8. Now, with both the upper and lower wings upside down (the edges should be curving up at this point), insert the back row of spars into the underside of the top wing. Use the marked holes as a general guide, but keep the spars straight and evenly spaced. Put a little glue on each to keep them in place as shown in the picture. Now join the front spars to the top wing, remembering to keep them straight and fasten them with dabs of glue. This takes some effort to get everything in the right place and is easier to do with two people.



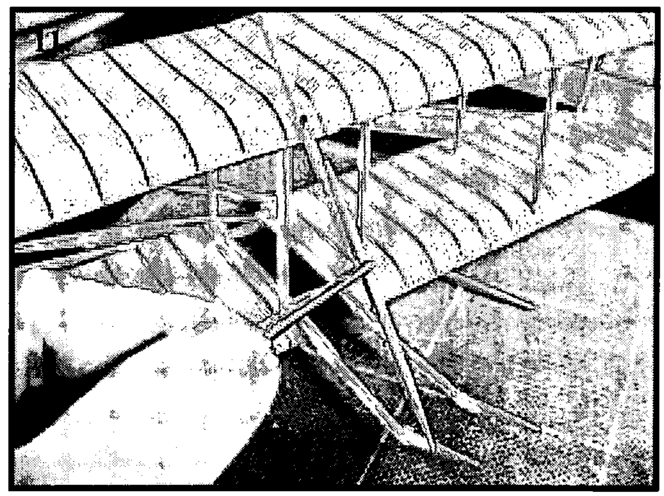
9. To make each of the two skids join two toothpicks end to end. When the glue is dry, trim them to a length of 3 inches (7.5 centimeters) and then glue the cutoff end back on at a 30-degree angle.



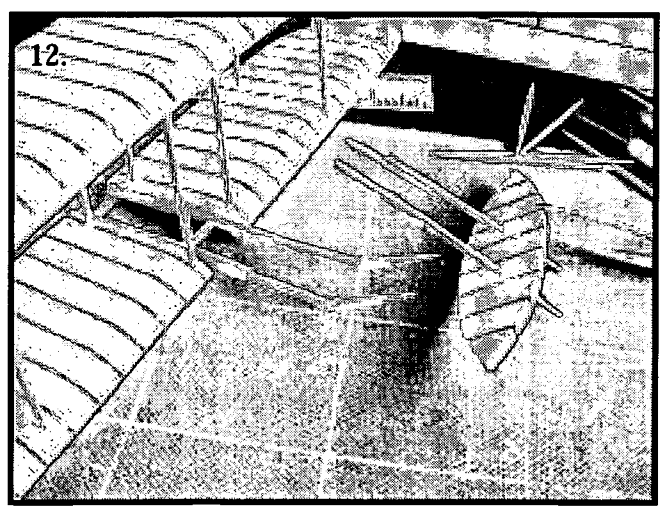
10. Glue the skids on either side of the opening in the lower wing so that the tips point upward. They should project out from the downward curving front surface.



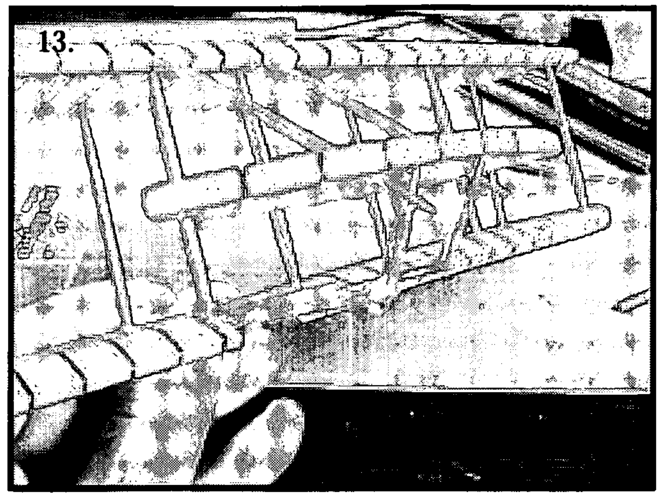
11. Cut a piece to brace across the skids and glue it at the 30-degree joint. Make two braces to go from the upper wing to the elevator by joining two toothpicks end to end and side by side to form a longer toothpick, and then mark them to the correct length by holding them between the upper wing and the skid, as shown. Allow enough to stick into the upper wing, cut off the excess, and then sharpen the cut end. (If the Styrofoam is thin, do not sharpen the cut end.)



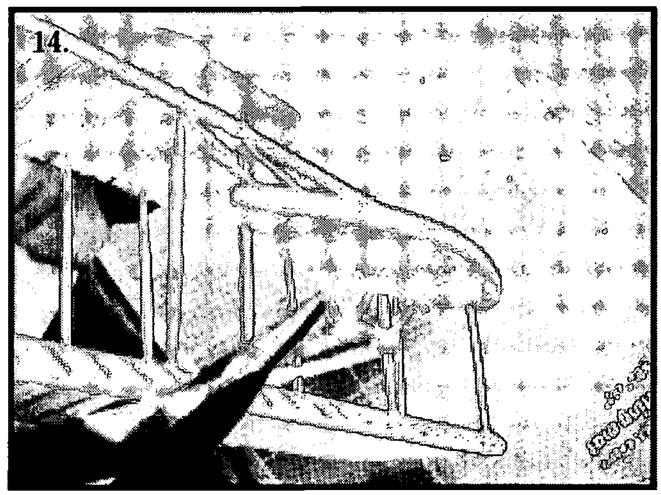
12. Push the ends of the uprights through the center of the elevator at an angle back toward the wing. Put glue on the top end of the upper braces and push them into the edge of the upper wing. (If the Styrofoam is thin, glue the ends of the uprights underneath the front edge of the upper wing.)



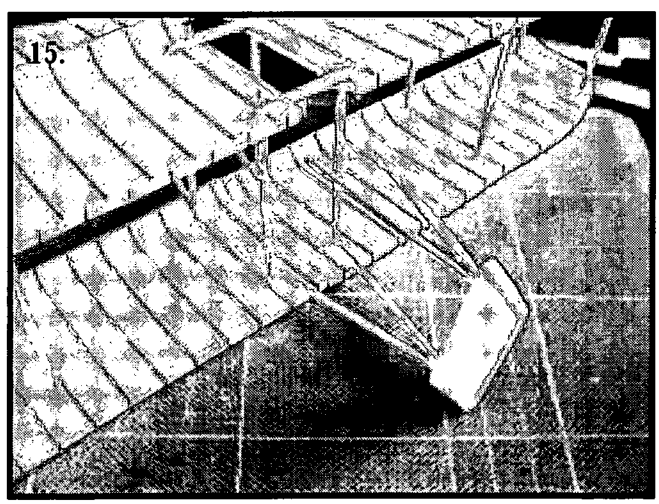
13. Now glue the lower end of the brace that sticks through the elevator to the upturned part of the skid in a way that makes the elevator level. Add a crossbar across the skids at the joint where the skids turn up at the 30-degree angle.



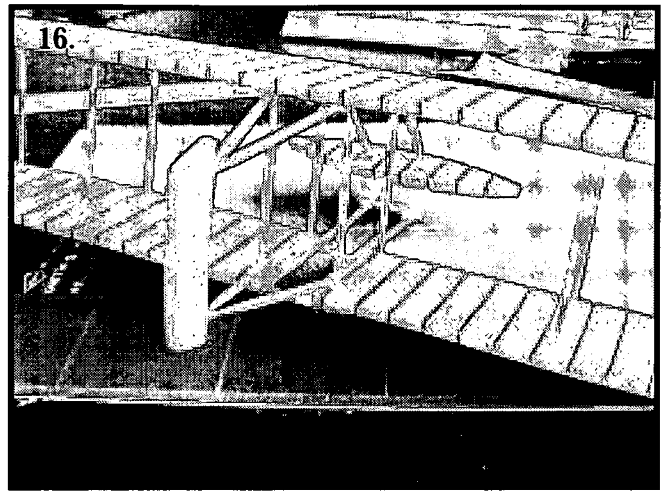
14. Cut two small pieces of toothpick long enough to go from the 30-degree joint to the rear of the underside of the elevator, and glue them in place. You may need to use tweezers or long-nosed pliers.



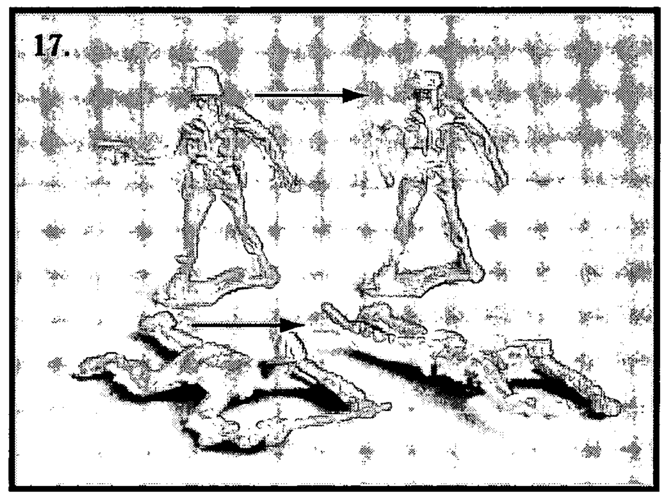
15. To attach the rudder, cut four toothpicks into 2-inch (5.5-centimeter) lengths, and stick the sharp ends into the long edge of the rudder, two on the top and two on the bottom so they form a "V" shape, as shown. The distance between the two legs of the V should be 3/4 inch (1.8 centimeters). Turn the glider over and glue the top two braces to the underside of the upper wing.

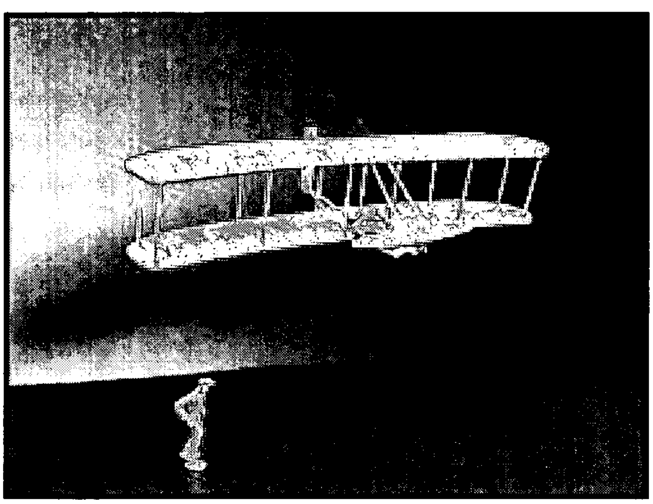


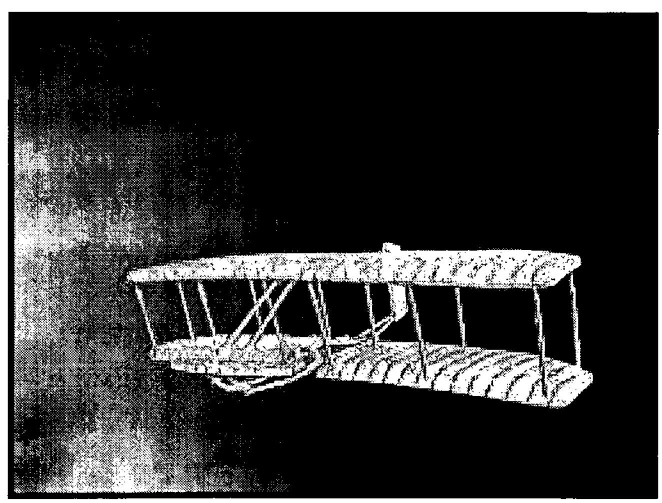
16. Turn the glider right side up and glue the bottom two rudder braces to either side of the opening in the lower wing. This finishes the glider.



17. (Optional) You can make the figures of Wilbur and Orville Wright by swapping and gluing parts of plastic army soldiers. To obtain the desired poses, arms and legs can be removed and some from other soldiers glued in their place. Guns and helmets should be trimmed away using a hobby knife and the figure arms and legs can be shaped, swapped, or repositioned to fit and glued on. Five-minute epoxy works best for this. The picture to the right shows how to make a pilot lay on the wing. The original soldiers on the left were transformed into the figures of Wilbur and Orville Wright on the right.







Wright Brothers 1903 Flyer

The Wright Brothers' 1903 aircraft was the first heavier-than-air, self-propelled, maneuverable, piloted aircraft. It was, in short, the first airplane.

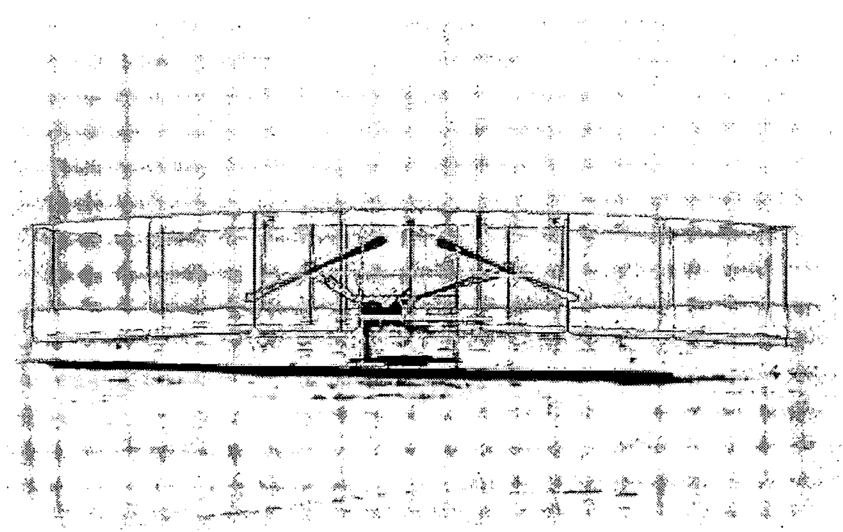
The forces acting on this aircraft were identical to the forces that act on any modern aircraft. The various parts of the aircraft were designed and perfected by 3 years of flight testing of unpowered kites and gliders and from wind tunnel testing. The Wrights used a moving elevator at the front of the aircraft to control pitch (an up or down movement of the nose). From the glider flights of 1901, the brothers identified the need for a rudder at the rear of the aircraft to control yaw (a side-to-side movement of the nose) and to allow coordinated turns. Control of roll (an up-and-down movement of the wing tips) was provided by wing-warping, which meant twisting the wing tips to increase or decrease lift on the outer sections of the wing.

The brothers began large-scale testing of their ideas with a combination kite and glider in 1900. The ideas tested on this aircraft were further refined on the glider of 1901, verified by the Wrights' wind tunnel data, and finally confirmed on the very successful 1902 Glider.

The 1903 aircraft (shown below) was similar to the 1902 craft, but now with a longer 40-foot wingspan, a 6-foot chord, 5 feet between the wings, and twin rudders and elevators. The biggest difference between the 1902 and 1903 aircraft was the addition of the propulsion system. The 1903 aircraft used twin pusher propellers located behind the wings. They were made to rotate in opposite directions, so that the rotational forces would cancel each other out. The Wright Brothers used gasoline to turn the propellers. Since no one could provide them with a lightweight motor of adequate horsepower, they built their own 4-cylinder, 12-horsepower motor. To put this into perspective, the motor of a modern lawn mower can easily achieve 6 horsepower.

The motor was placed on the lower wing next to the pilot and connected to the propellers with bicycle chains. A small gasoline tank was mounted on one of the wing struts. With the pilot and motor, the 1903 craft weighed a little over 700 pounds. This aircraft was first successfully flown on December 17, 1903, at Kitty Hawk, NC, on four flights from about 100 to over 800 feet.

Each of the four flights was marked by an instability in pitch; the nose, and consequently the entire aircraft, would slowly bounce up and down. On the last flight, hard contact with the ground broke the front elevator support, damaged the engine, and ended the season's flying. The brothers were encouraged, but realized that there was still more work to do before a truly operational aircraft could be developed. They continued to perfect their design through 1904 and 1905.



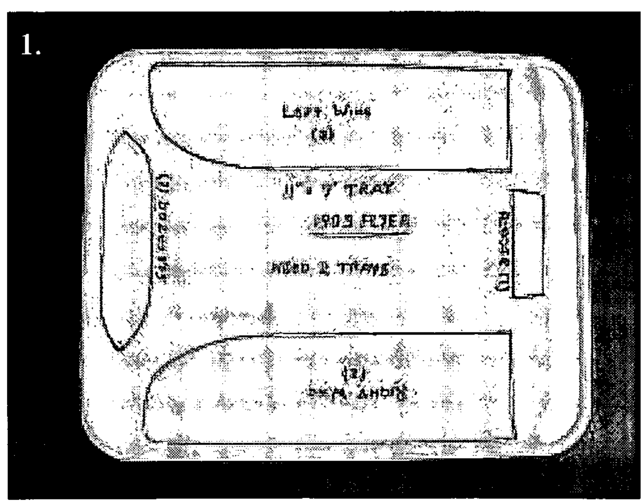
Wright Brothers 1903 Flyer Model Instructions

Designed by
Roger Storm, NASA Glenn Research Center

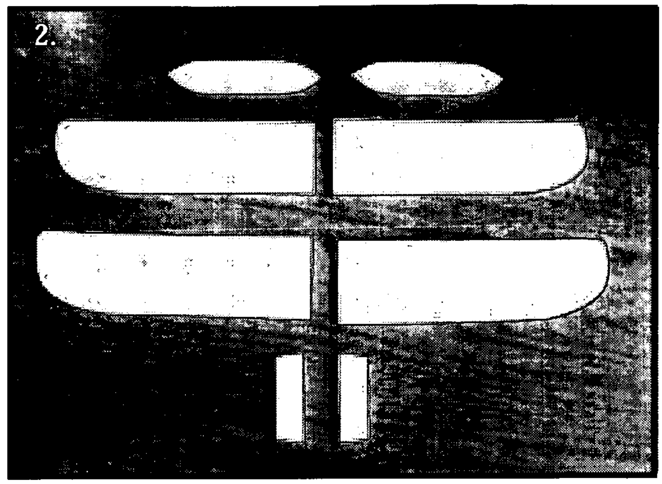
Materials
- Two to three clean Styrofoam meat trays, at least 9 inches (23 centimeters) by 11 inches (28 centimeters), preferably white
- 40 to 50 toothpicks
- 30-inch piece of 1/8- by 1/8-inch (.3 centimeter) piece of balsa wood
- Two craft sticks or wooden ice cream sticks
- Low-temperature glue gun
- Scissors
- Hobby knife, razor utility knife, or single-edge razor blade (adult help here)
- Cardboard or board to cut on
- Ultrafine-tip black marker
- Ruler
- Emery board
- Manila file folder
- Clear plastic sheet, such as a transparency sheet for an overhead projector
- Small plastic toy army soldiers, about 2 inches (5 centimeters) tall (optional)

General Instructions
- Use scissors to cut out all three templates on the heavy lines of the 1903 Flyer template (found in the back of this book).
- Do all hobby knife or razor blade cutting on the board or cardboard to protect your working surface.
- The finished model is for display only; it is not meant to fly.

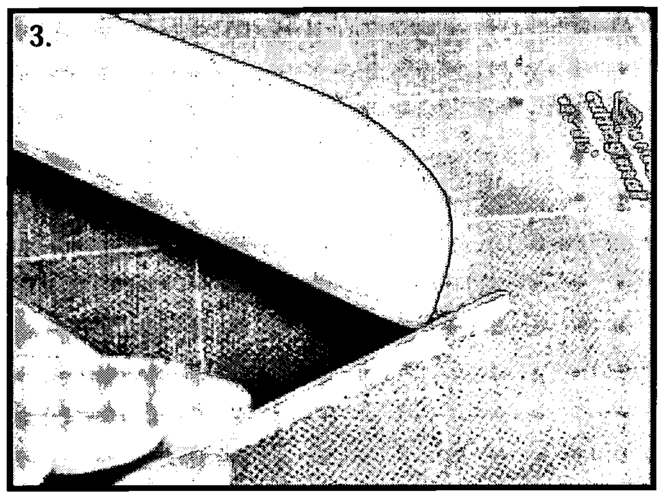
Procedure
1. Carefully trace the wing and elevator shapes on the inside of the two Styrofoam trays as shown. Be sure the front edges of the wings go about two-thirds of the way up the curved sides of the tray. Check the bottom of the tray and avoid any logo found there. Cut out the wings and elevator with the hobby knife or scissors. Use the emery board to smooth the cut edges and sand off the pen lines.

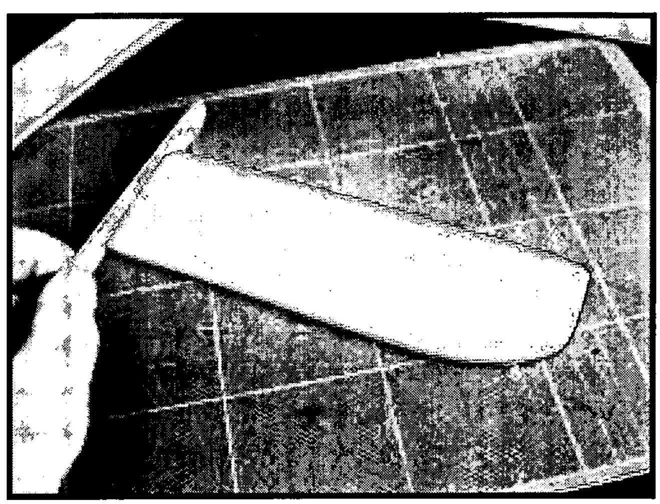


2. When finished you should have these parts, as shown.

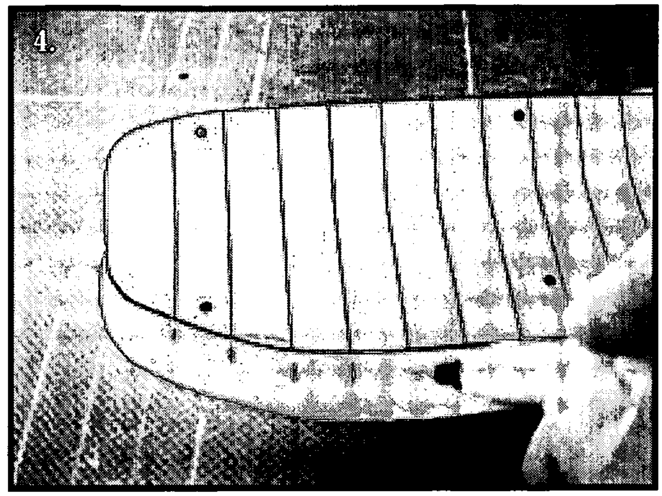


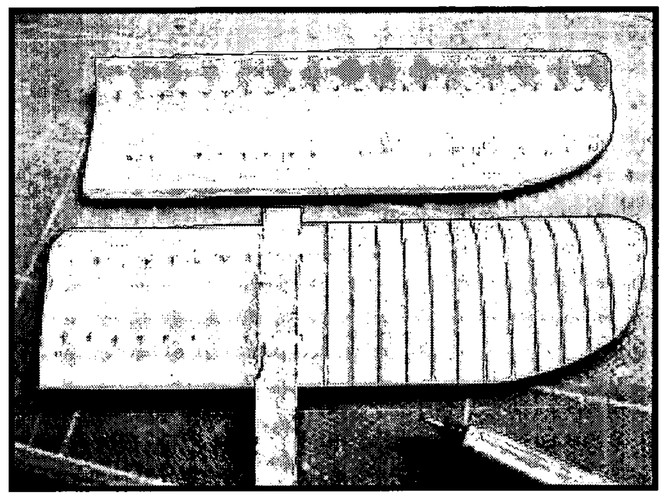
3. Using the emery board, make sure that the two halves of the upper and lower wings are flat where they will be joined, as shown at the lower right.



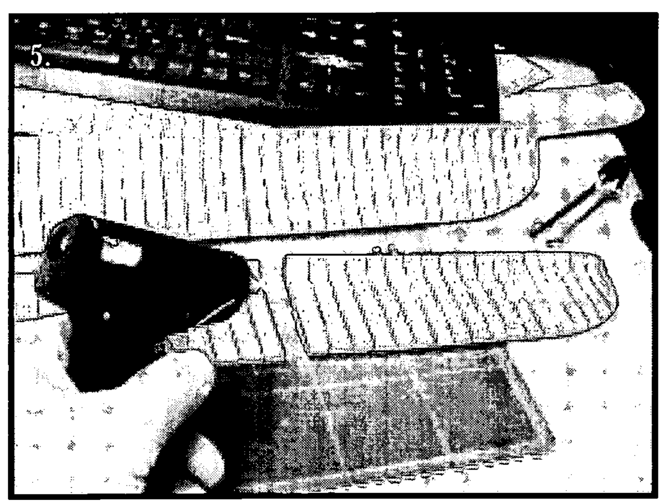


4. Using the templates as a guide, mark the locations of the rib lines on the tops and bottoms of the wind and elevator sections with the ultra-fine tip black marker. Make two sets of marks, one on each edge. Connect the marks to make the rib lines. Make a rib template from a manila folder to draw the rib lines (so the end of the template can be bent to conform to the rounded shape of the Styrofoam).

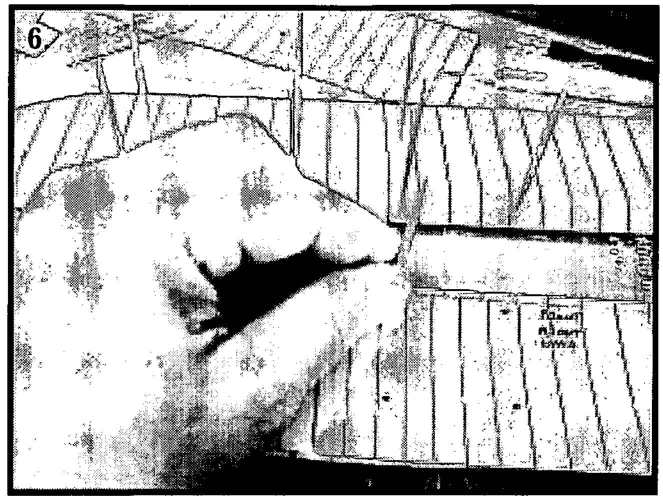


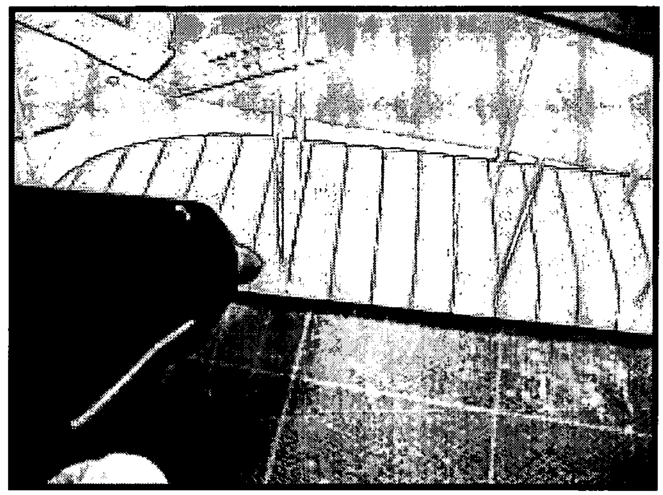


5. Place glue on the flat edge of the upper and lower wing halves and join each wing as shown.

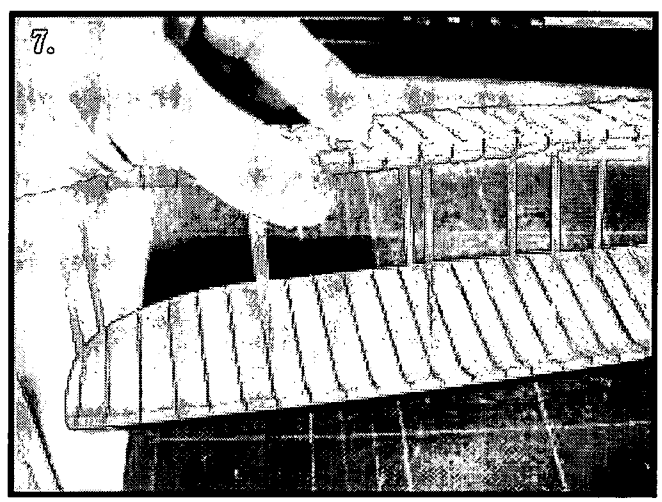


6. Use the wing template and a sharp toothpick to mark the holes for the spars on the top surface of the lower wing. Note that the front edges of the wings curve down. Dip toothpicks into glue and set them upright in the lower wing. Try not to push them all the way through the wing. Be sure they are straight and let them dry.

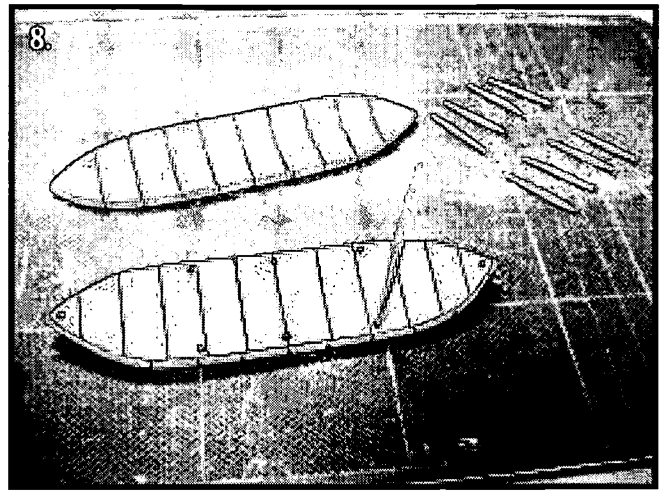




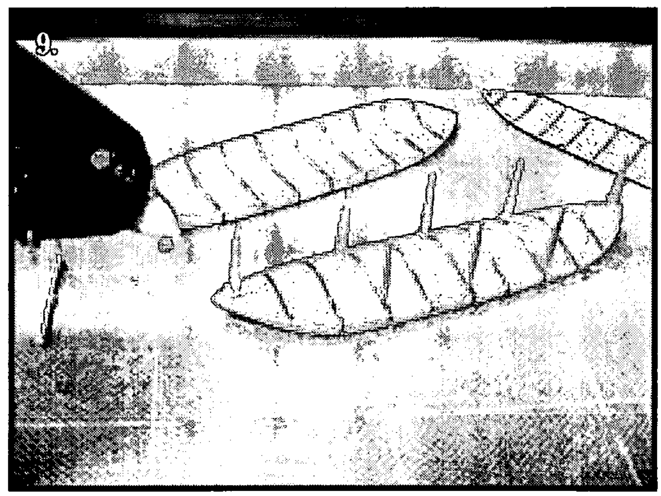
7. Now turn the lower wing upside down and insert the spars into the underside of the upper wing, doing the back row (away from the curved edge) first. Be sure each is vertical and add a little glue to hold each in place. Now tip the wing forward and insert the front row of spars, working from one end to the other. Again, try not to push them all the way through the wing. It takes some effort to get each in the right place and vertical. Add a dab of glue at the top of each spar to help secure it to the upper wing.



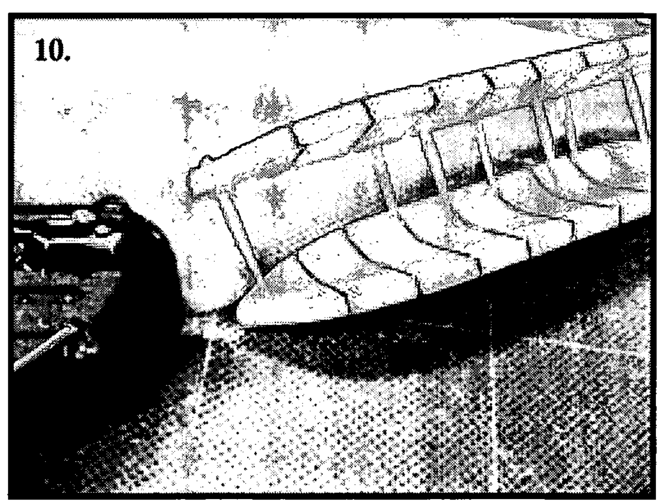
8. For spars for the elevator, cut eight toothpick sections, each 1 inch (2.5 centimeters) in length, and sharpen the cut ends. Mark the locations for these spars on the upper surface of the lower elevator using the template, just as you did with the wings.



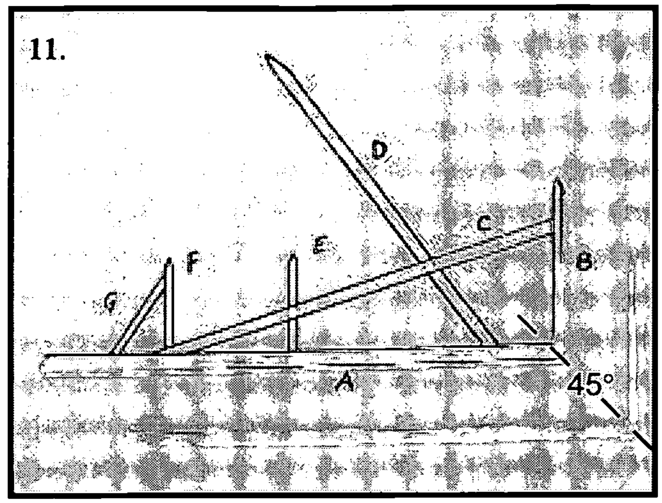
9. Set the eight short spars into the top surface of the lower elevator and add a bit of glue to each at the base, as shown.



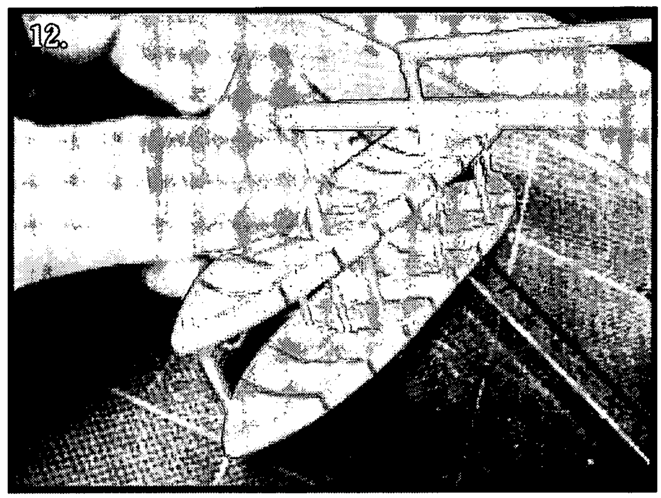
10. Turn the lower elevator assembly over and insert the spars into the underside of the upper elevator, doing the back row first and then the front, trying not to go all the way through the Styrofoam. Anchor with glue.



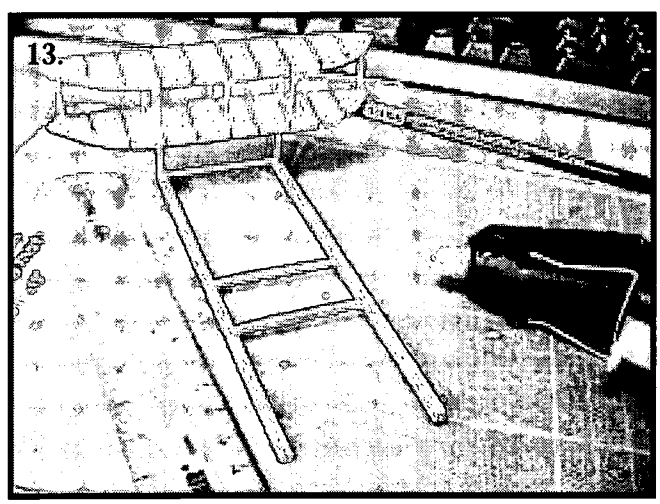
11. Cut a 5.5-inch (14-centimeter) piece of the balsa wood for section A of the skid (from the skid template) and lay it on the template. Cut the right end to form a 45-degree angle at the very end. Cut a toothpick for section B to a length of 1.8 inches (4.5 centimeters), also cutting the end of it at a 45-degree angle. Glue the 45-degree ends of the toothpick and the balsa wood piece together to form a 90-degree angle, as shown. Make a second skid by repeating the process.



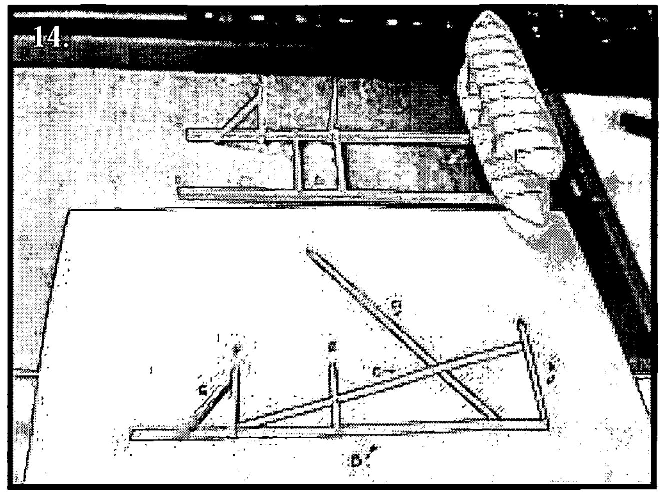
12. Turn the elevator assembly over and poke two holes through the lower elevator, midway between the front and rear spars of each of the spar pairs that are next to the center pair of spars (near the third rib mark from either end). Push the top of the skid assembly through the hole just made, add a bit of glue, and then stick the skid into the upper elevator. Repeat with the second skid as shown.



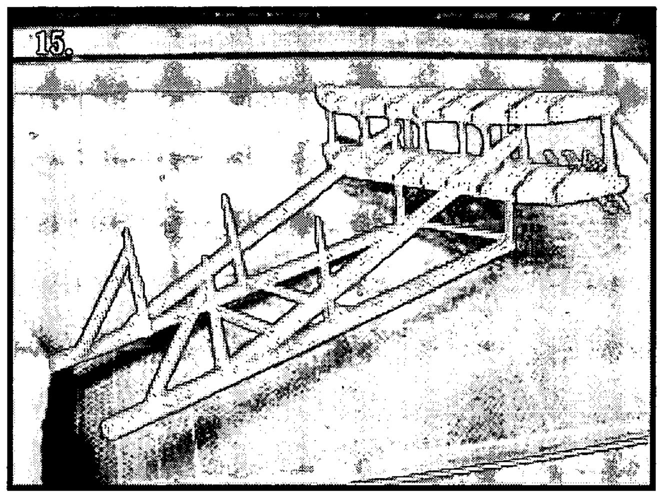
13. Cut the pointed ends off of three toothpicks so that they are 1.8 inches (4.5 centimeters) in length and place them as cross-braces across the skids as shown, one at the right angle of the skid, one at 2.8 inches (7 centimeters) from the right angle, and one at 3.5 inches (9 centimeters).



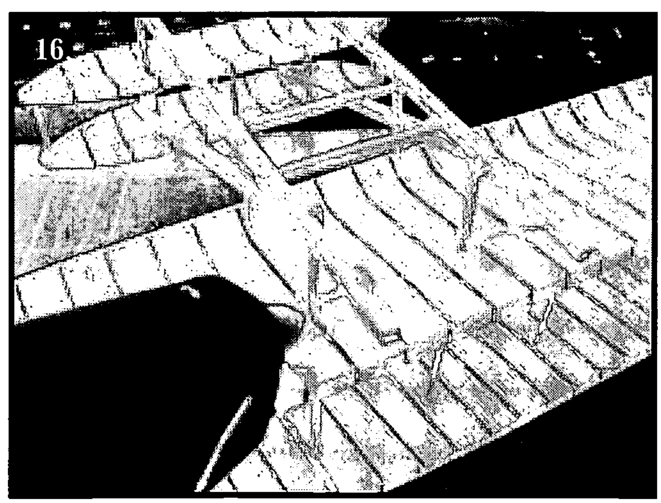
14. Cut two toothpicks to a 1.2-inch (3-centimeter) length. Glue them to the skid as shown on the template at points E and F, pointed ends up. Now measure and cut another toothpick as the rear brace (section G) and glue it in place. Repeat for the second skid.



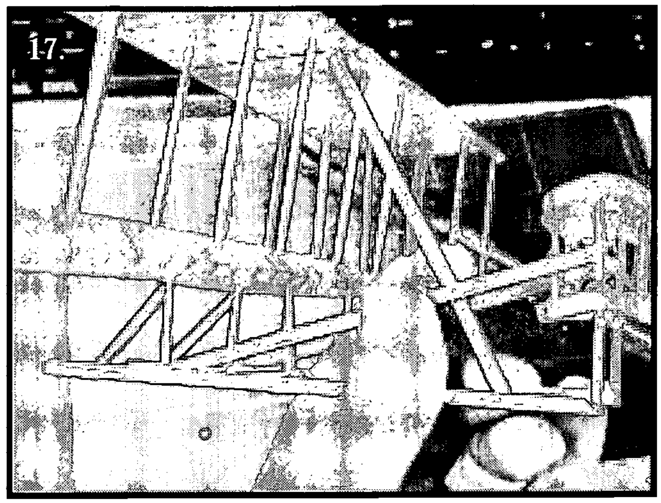
15. Now cut two balsa braces (section C) to go from the rear skid support up to the elevator support. Glue them in place as shown.



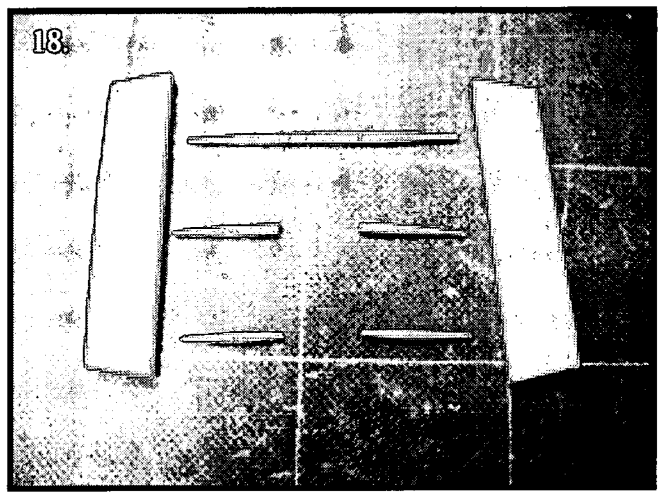
16. Turn the wing assembly over and press the skid assembly into the center of the lower wing as shown. Be sure the elevator projects out from the curved edge of the wing. Try to keep the toothpicks from going through the Styrofoam. Add some glue to each support.



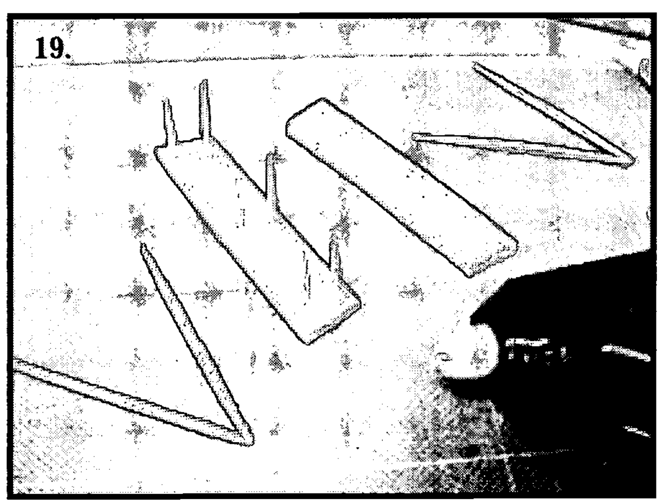
17. Cut two 4-inch (10-centimeter) pieces of balsa for section D and sharpen one end of each. Glue one end under the leading edge of the upper wing between the center and next-to-center spar, and then glue the other end to the bottom skid. Repeat on the other side of the skid.



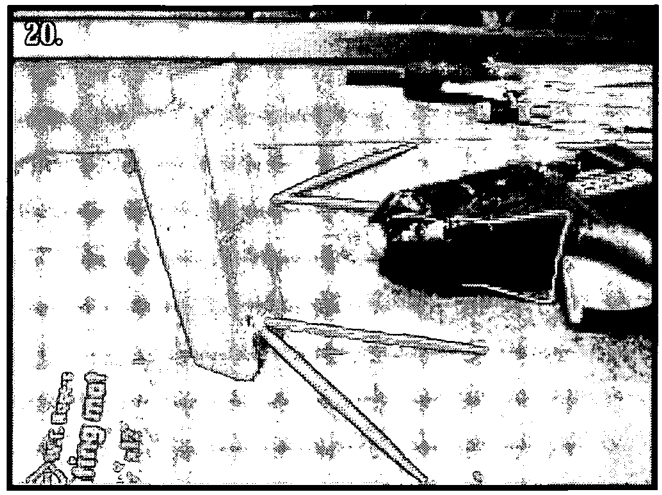
18. Six .8-inch (2-centimeter) rudder braces are needed. Cut them from three toothpicks as shown and sharpen the cut ends.



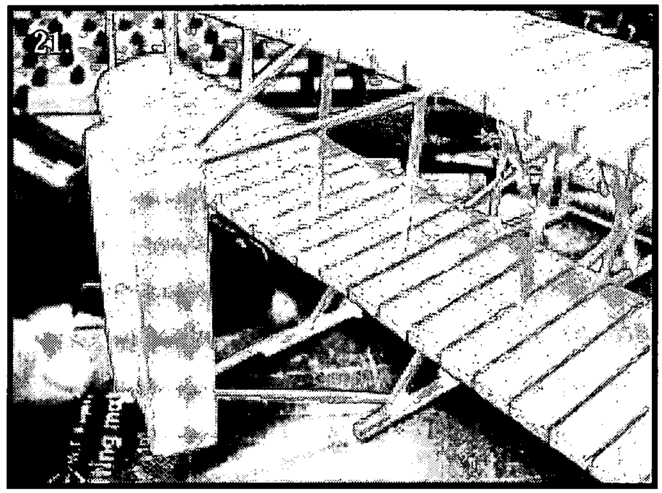
19. Dip the braces in glue, insert them into the rudder as shown here, and then turn the assembly over and insert the braces into the other rudder. Add more glue for support. To attach the rudder to the flyer, make two sets of V-shaped braces by gluing together two toothpicks as shown. The distance between the two legs of the V should be 1.5 inches (3.8 centimeters).



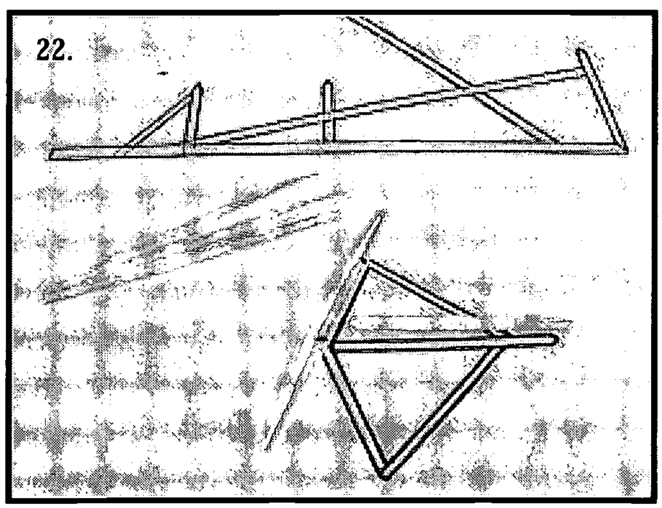
20. Glue the V-shaped braces to the rudders as shown. Once the glue is set, turn the rudder assembly over and glue on the other brace.

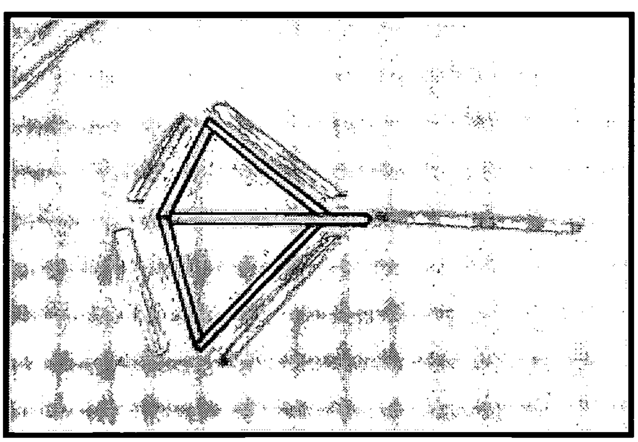


21. Stick the upper brace ends into the rear edge of the upper wing as shown and add a spot of glue. (If the wing is thin, glue the brace under the wing.) Now glue the ends of the lower brace to the rear of the skid so that the rudder is vertical.

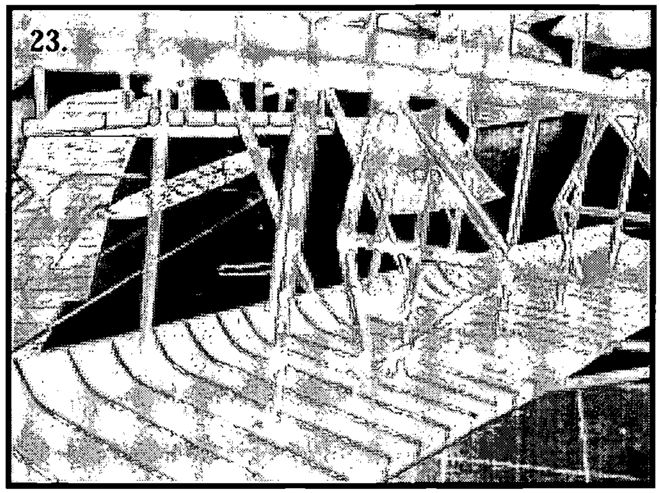


22. To make the propeller supports, use the template to mark and cut five toothpicks for each. Try to keep the assembly flat as it is glued.

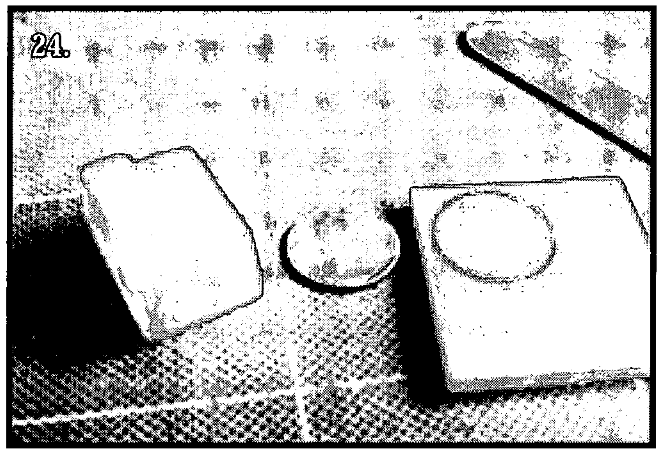




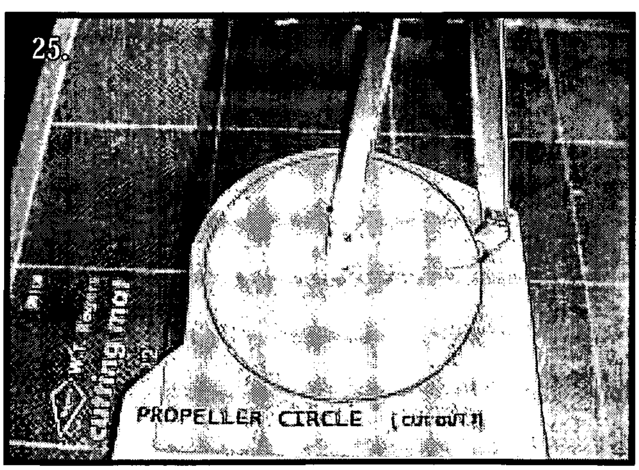
23. When dry, glue each propeller support to the lower wing 2.2 inches (5.5 centimeters) from the center, in line with the back struts. Turn the flyer over and glue to the top wing so that the support is vertical. Extra glue may be added to fill in any gap.

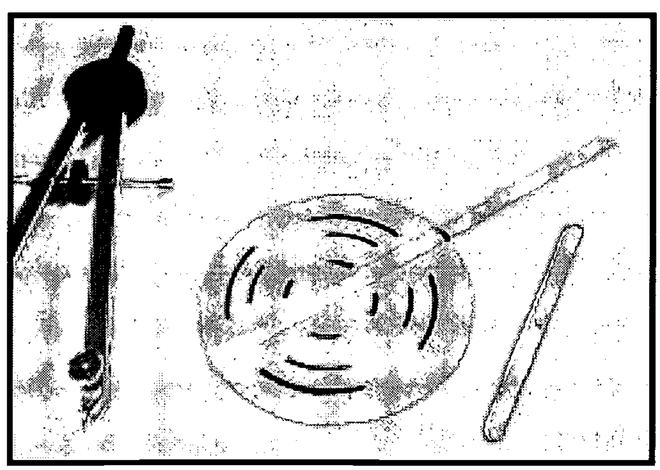


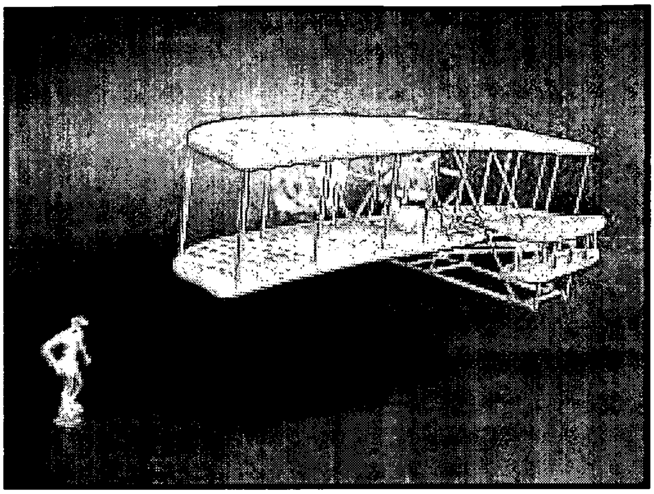
24. Simulate the small engine by gluing two .8- by 1.2-inch (2- by 3-centimeter) pieces of Styrofoam together and then adding a .4- by 1.2-inch (1- by 3-centimeter) piece on top. Trace and cut a circle with a penny or dime, cut out, and then glue on the end of the engine. Glue the engine onto the lower wing just to the right of center.

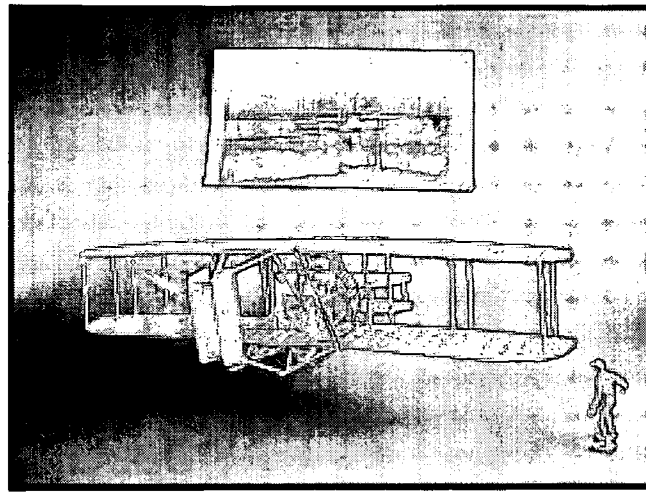


25. To simulate a turning propeller, trace and cut two 2.8-inch (7.2-centimeter) circles out of stiff clear plastic, such as a piece of a blank transparency sheet for an overhead projector. Draw pieces of smaller circles on the plastic circle with the black marker. Make a small hole in the very center of each circle with a toothpick. Make a propeller blade from a thin craft stick or wooden ice cream stick by cutting a piece the diameter of the plastic circle, rounding the cut edge, and poking a hole in the center. Mount the plastic circle and then the propeller blade on the end of the propeller support and add glue. Make another propeller sheet and blade for the other side.

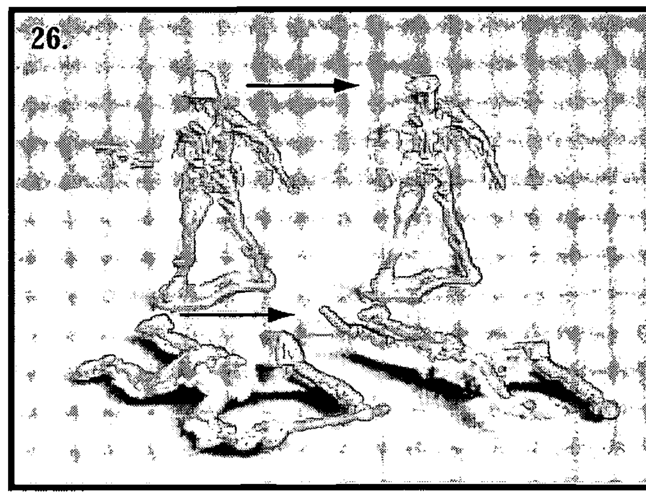








26. (Optional) You can make the figures of Wilbur and Orville Wright by swapping and gluing parts of plastic army soldiers. To obtain the desired poses, arms and legs can be removed and some from other soldiers glued in their place. Guns and helmets should be trimmed away using a hobby knife and the figure arms and legs can be shaped, swapped, or repositioned to fit and glued on. Five-minute epoxy works best for this. The picture to the right shows how to make a pilot to lay on the wing. The original soldiers on the left were transformed into the figures of Wilbur and Orville Wright on the right.



Glossary of Terms

Adverse yaw: When adverse yaw occurs, the nose of the plane turns left when the pilot intends it to turn right, and vice versa.

Aerodynamics: A field of fluid dynamics that studies how gases, including air, flow and how forces act upon objects moving through air.

Aeronautics: The science of making and flying aircraft.

Aft: Toward the rear of the aircraft.

Aileron: The Wrights' "wing-warping" technique was the forerunner to the modern "aileron," which performs the same function. An aileron is a hinged flap on the back edge of the wing of an airplane; it is moved up or down in keeping the airplane steady or making a turn in the air. When flying straight and level, moving the control stick to the right will raise the aileron on the right wing and lower the aileron on the left wing. This will cause the aircraft to roll to the right.

Airfoil: The wing of an aircraft or something shaped like a wing, like the blades of a propeller.

Aspect ratio: Ratio of wingspan to wing chord or width.

Ballast: Something heavy to improve the stability and control of an aircraft or control the ascent of an air balloon.

Balloon: A large bag or rubber sack that is filled with air or other gases that cause it to rise and float in the air. A balloon is a "lighter-than-air" aircraft.

Camber: The convexity of the curve of an airfoil from the leading edge to the trailing edge.

Canard: A small airfoil in front of the wing of an aircraft that increases the aircraft's stability.

Chord: The straight line distance joining the leading and trailing edges of an airfoil.

Cockpit: A compartment in the front of the airplane from which the flight crew flies the aircraft.

Drag: The retarding force acting on a body (like an airplane) moving through a fluid (like air) parallel and opposite to the direction of motion.

Elevator: A part of the tail of an airplane that can be moved to control the airplane's up or down motion, or pitch.

Fuselage: The main structural body of an aircraft to which the wings and tail are attached.

Glider: An aircraft that has no engine and is carried along by air currents.

Heavier-than-air: A craft that needs power to become airborne and does not float by itself like an air balloon.

Horsepower: A unit of measurement based on the power that a horse exerts in pulling.

Kite: A tethered glider that is lifted by the wind. A kite was the first heavier-than-air aircraft.

Lift-to-drag ratio: The amount of lift that is achieved compared to the amount of drag on an aircraft.

Lighter than air: A craft like an air balloon that is lighter than air and naturally rises.

Pitch: A rotational motion in which an airplane turns around its lateral axis (major down movement of the nose). Pushing forward on the control stick will lower the elevators, which forces the tail upward. The pilot will then see the nose of the aircraft fall, or "pitch."

Roll: A rotational motion in which the aircraft turns around its longitudinal axis (an up-and-down movement of the wing tips). Pushing the control stick to the left will raise the aileron on the left wing and lower the aileron on the right wing. This will cause the airplane to roll to the left. The pilot will see the left wing tip fall and the right wing tip rise.

Rudder: A control surface on the trailing edge of the vertical part of the tail that is used to make the aircraft "yaw." The rudder is controlled by rudder pedals. Pushing the left rudder pedal will tilt the rudder to the left. This will cause the nose of the aircraft to turn to the left.

Self-propelled: An aircraft that has a source of power like an engine.

Stabilizer: A surface that helps to provide stability for an aircraft. An airplane has two stabilizers: a vertical stabilizer and a horizontal stabilizer. Stabilizers are like the feathers on an arrow, which keep the arrow pointed in the right direction.

Struts: Structural pieces added to provide support and designed to resist pressure in the direction of their lengths.

Torque: Rotational force about an axis.

Warping: Twisting of the wing surface, as the Wrights described it.

Wind tunnel: A small or large tunnel with a fan that can create constant wind conditions for research purposes.

Yaw: A rotational motion in which the aircraft turns around its vertical axis, or from side to side. This causes the aircraft's nose to move to the pilot's right or left. Pushing the right rudder pedal will tilt the rudder to the right. The pilot will see the nose of the aircraft turn to the right.

Activity Answers

Activity 1 answers

Before you go to Dayton to investigate the Wright Brothers, it is important to do some research and get some background information. You need to go to the library and/or the Internet and find out about the progress of attempts to build a flying machine up to the year 1900. Write a short paragraph about each of the following and their accomplishments up to 1900:

1. Otto Lilienthal 2. Octave Chanute 3. Samuel Langley

See whether you can answer the following questions:

1. Why do you think some of these early pioneers were using gliders instead of powered aircraft? Why didn't their craft have engines?
   The glider wings they had constructed could not provide enough lift to handle the weight of the pilot plus the weight of the engine.

2. What was the record for distance and time aloft by a manned glider in 1900?
   d. Otto Lilienthal had glided over 1300 feet and stayed aloft 12 to 15 seconds.

3. Why was gliding so dangerous at the time?
   Fliers did not understand how to control the gliders in the air. Lilienthal thought that just by shifting his weight he could control the direction the glider flew. This proved to be inadequate, and he crashed from a height of over 50 feet. Pilcher also died in a similar fashion.

4. Why do you think Chanute chose to test his gliders at the Indiana Dunes on the southern shore of Lake Michigan?
   There are steady winds coming off the lake, which are needed to fly a glider. There were also hills (dunes) from which to launch and soft sand to land on.

5. How far is it from Cincinnati to Dayton? How do you think you might have travelled there in 1900?
   49.5 miles, travel by train.

Activity 2 answers

Now that you know something about the state of flying machines in 1900, pretend that you are a reporter for the Dayton Daily News. You are being sent to interview the Wright Brothers. What questions do you think you'd want to ask them about what they are attempting to do?

Student answers will vary.

Some possible questions might be

How will you control your glider?
Where will you fly?
Are you going to try to use a motor?
Who will be the pilot?
Are you afraid?
How will you get your glider into the air?
How will you land without getting hurt?
What materials will you use to construct the glider?
How are you going to finance your experiment?
If you succeed, what will you do with your invention?
How high and how far would you like to fly?
How will you record your progress? Will you take pictures?
How will you take off?

Activity 3 answers

1. From your trip, why do you think Wilbur was flying a large kite in the summer of 1899? What do you think he learned from doing it?
   He was learning how to control an object in the air.

2. Having arrived back in Cincinnati after visiting the Wrights in Dayton, you must make a written report to the Scientific Society. What are the key points that you need to report?
   A. The Wrights have learned to control a craft in the air by twisting the wings.
   B. They have constructed a very large craft to test their ideas.
   C. They will be testing somewhere in North Carolina in the fall.

3. Why do you think the Wright Brothers are headed to North Carolina? What kind of conditions do you think they are seeking to carry out their glider experiments?
   They are going to Kitty Hawk in North Carolina because it has nearly constant high winds, the strongest in the country. There are also hills (dunes) from which to launch, sand to land on, and few trees to crash into.

Activity 5 answers

Your report to the Cincinnati Scientific Society stimulates a lot of discussion. The members have many questions as they try to understand the Wright's experiments. How do you think you would answer this sampling of their questions?

1. Why did the Wrights use a two-wing (biplane) arrangement?
   Two wings provide twice the amount of lift.

2. What was the purpose of having the wings be curved or arched?
   Giving the wings a curved surface (called camber in modern planes) causes the air to turn as it flows over the wings, and this provides lift.

3. Why did the pilot of the Wright Glider lie down on the wing instead of hanging from the glider, as in Lilienthal and Chanute's gliders?
   Lying down on the wing greatly reduces wind resistance. It also makes control of the glider easier to achieve and protects the pilot from hard landings.

4. Why do you think twisting the wings caused the glider to drift left or right? How much did the wings twist? If they stayed twisted, do you think the glider would fly in circles or crash? Why?
   Twisting the wings changes the amount of lift they provide, so the craft rolls left or right. The wings only need to twist a small amount to cause a roll. If the wings stay twisted, the glider is likely to crash. For a glider to fly, it needs to stay facing into the wind like a kite, so it would not be able to circle.

Activity 6 answers

Orville told you that he and Wilbur are determined to create a flyable machine, and that to do this they are going to have to get more lift out of their craft so it can support a pilot. When you report this to the Cincinnati Scientific Society, the members start to debate about what they think is the best way to accomplish this. It is decided to have a contest to see who can produce the best design to improve upon the Wright Glider.

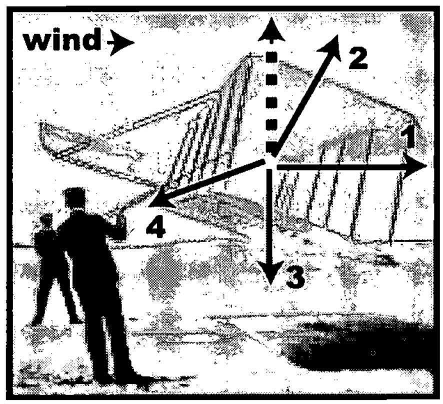
1. If you were to enter this contest, what specific changes would you make to give the 1900 Glider more lift? **Answers will vary. Longer wings, wider wings, more curved wings, lighter weight material**

2. How do you think each change would improve the original design?
   Answers should focus on providing more lift through bigger wings and/or less weight.

3. This is a drawing of the 1900 Glider. It had a wingspan of 17 feet and a wing area of 165 square feet. On another sheet of paper draw a sketch of your proposed glider, showing a top view and a front view. Be sure to put dimensions on your sketch. How long, wide, and high will your glider be?
   See student drawings. They should have two views and labeled dimensions.

Activity 8 answers

The picture below shows the Wright Brothers at Kitty Hawk, NC, with their 1901 Glider being flown as a kite. It weighed 98 pounds and had a wingspan of 22 feet. The kite appears to be floating in the air, but it is actually being held motionless because the forces that are acting on it are "balanced."



1. You know that wind is needed to fly a kite, so draw an arrow on the picture to show which way the wind would be pushing on the glider.

2. There are three other forces that are acting on the kite. One of these is the lift caused by the wind acting on the wings of the glider. Draw an arrow to show the direction that this force acts on the glider.

3. The third force acts on you and all other objects on Earth all the time. It is called <u>**gravity**</u>. Draw an arrow to show the direction that this force acts on the glider.

4. Look at the men in the picture and see if you can determine the direction of the fourth force. Keep in mind that the glider is motionless, so the fourth force must act to balance out the other three forces. Draw an arrow to show the direction of the fourth force.

5. Do you see anything in the picture that shows that all the forces are canceling each other out? If yes, what is it? **Yes, because the glider is not moving.**

6. If the speed of the wind increased, what would happen to the glider? **The glider would fly up and away.**

Activity 9 answers

The report of the summer of 1901's activities caused quite a stir in the Cincinnati Scientific Society. When you mailed sketches of the new craft back in July, many members had thought that the additional surface added to the wings would provide the lift needed. Clearly something was wrong.

1. Why do you think that the new glider with its larger wings failed to perform as expected?
   Answers will vary. Some possibilities might be that it was too heavy, the wings weren't curved enough, the big wings caused too much drag, inaccurate design data, etc.

2. If you were Wilbur or Orville Wright, what would you do at this point? Why would you do this?
   Answers will vary. Some possibilities might be to quit, ask an expert for help, do more research, change the wing shape, change the wing size, make it lighter, reevaluate your data, etc.

3. To solve a problem, the Wright Brothers would only make a single change at a time. Why is this a scientific way to do an experiment?
   Because if there is a difference in data after making a single change, it will be clear why it happened.

Activity 10 answers

Advances in science are often hindered by making wrong assumptions, making assumptions based on incorrect information, or by not understanding information or data in the right context. The Wright Brothers thought the reason their 1901 Glider did not perform up to expectations was that Lilienthal's data, on which they had based their calculations, were wrong.

Choose one or more of the following ideas that were once accepted as correct in science. Find out who challenged these ideas and how our thinking changed as a result. Write down your answers.

1. The Earth is flat.
   Answers will vary. Eratosthenes used the Sun shining into a well to calculate the Earth's diameter in 230 BC. Columbus did not sail off the edge of the Earth. Magellan was able to circumnavigate the Earth.

2. The Sun revolves around the Earth.
   In 1530, Nicolas Copernicus showed that the Earth revolved around the Sun in addition to turning on its axis. Galileo observed moons orbiting Jupiter in 1630.

Activity 11 answers

The Wright Brothers are credited with a number of "firsts" in the science of aeronautics. One of these firsts was using a wind tunnel of their own design (a 6-foot long rectangular box) to gather data and to design wing shapes (called airfoils). Wind tunnels are still used for many kinds of research. Some of them are very large; some are supersonic; some are very cold; and some simulate very high altitudes.

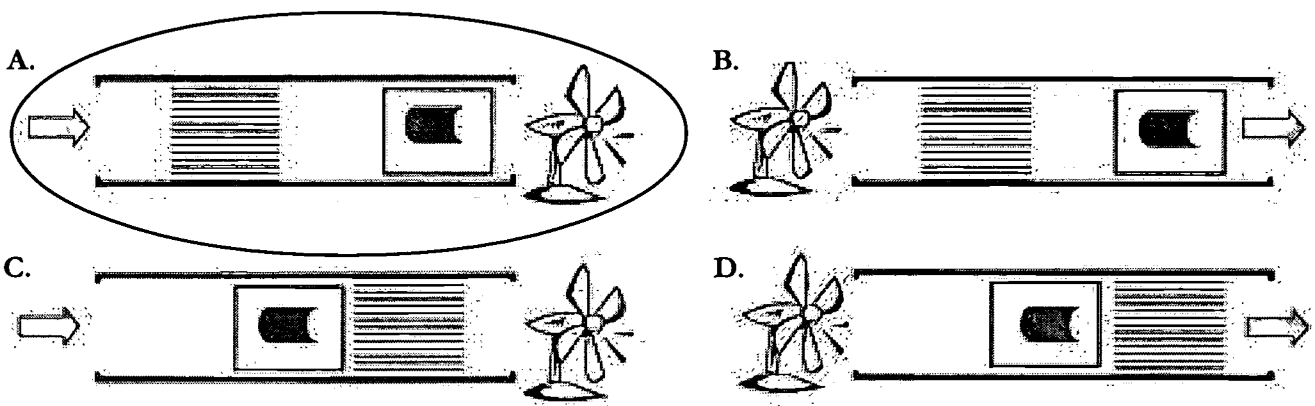
1. Why did the Wrights construct their own wind tunnel?
   Because they wanted to gather their own aerodynamic data. They wanted to test the Lilienthal data. They did not understand how to apply the Lilienthal data.

2. When they ran their tests, the Wrights only allowed one person in the room and that person always had to stand in exactly the same place. Why do you think they had to take this precaution?
   Constant conditions are required to get consistent data. If a person moved, the airflow through the wind tunnel could be changed.

3. A grid was placed in the end of the box where the air entered. What function would you guess this served?
   The grid served to straighten the airflow. If the air swirled around, the conditions would not be constant.

4. What advantages are there to testing airfoils in a small box? (Try to list at least three.)
   1. It is cheaper to build models than full-size aircraft.
   2. It is safer to test a bad model than to fly a bad airplane or glider.
   3. It takes less time to test several designs.
   4. It is faster because the wind is constant in the tunnel and unpredictable outside. You don't have to wait for good weather.
   5. It is easier to change or modify designs.

5. If you were to try to get good data on how well a wing design worked, which of the following wind tunnel arrangements do you think would be the best?
   "A" would be the best wind tunnel design.

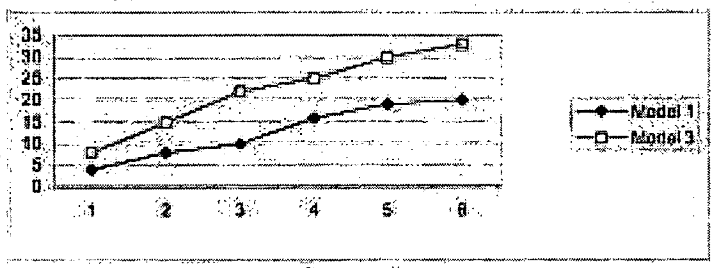


What factors made you decide on this as the best design?
The air is pulled through the grid to straighten the flow before it goes over the model. That way, it has the least turbulence.

Activity 12 answers

PART A.

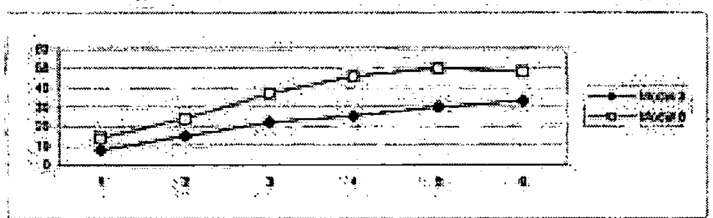
Angle of attack		Model 1	Model 3
3		4	8
6		8	15
9		10	22
12		16	25
15		19	30
18		20	33



Long, thin wings provide more lift.

PART B.

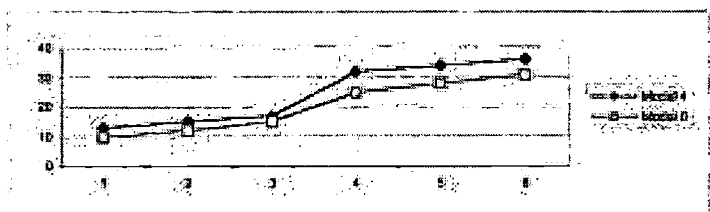
Angle of attack		Model 3	Model 9
3		8	14
6		15	24
9		22	37
12		25	46
15		30	50
18		33	48



Curved wings provide more lift than flat wings.

PART C.

Angle of Attack		Model 4	Model 6
3		13	10
6		15	12
9		17	15
12		32	25
15		34	28
18		36	31



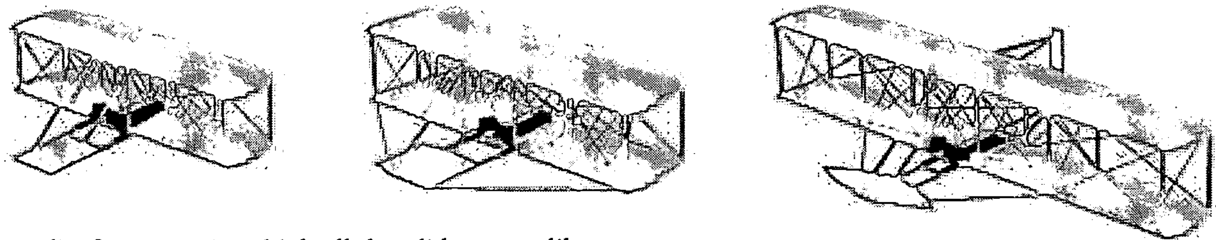
More curve is slightly better than less curve.

Part D.

Students should recognize that a glider with long, slender, curved wings is more efficient.

Activity 14 answers

Below are drawings of the gliders the Wright Brothers tested in 1900, 1901, 1902. Notice that Wilbur Wright is the same size in all three, which means all three are drawn to the same scale.



1. Try to list five ways in which all the gliders are alike.
   Answers will vary. Some possible answers could be that they all have two wings. They all have a pilot lying on the lower wing. They all have a small wing in front, etc.

2. What are some of the ways that they are different?
   Answers will vary. Some possible answers could be that they are different sizes. They have different wingspans. The small front wing is shaped differently, etc.

3. The 1901 and the 1902 gliders both have about the same wing area and they weigh nearly the same. Why do you think the 1902 is a better glider?
   The wings are longer and thinner. This gives the glider more lifting force and less drag.

4. Notice that in all three gliders, Wilbur is lying down. What do you think the effect would be if he sat up while flying them?
   If he sat up he would cause more air resistance. This would slow the glider down.

Activity 15 answers

1. If you made $100 a month in 1900, and a camera cost $1, what percentage of your monthly salary would it take to buy a camera in 1900?
   1 percent

2. If your yearly salary today is $36,000 and you want to buy a camera that costs $100, what percentage of your monthly salary would you have to spend? How does this compare to 1900?
   Your monthly salary would be $3000. You would have to spend about 3.3 percent of your salary to buy a $100 camera. The Brownie was much cheaper in 1900.

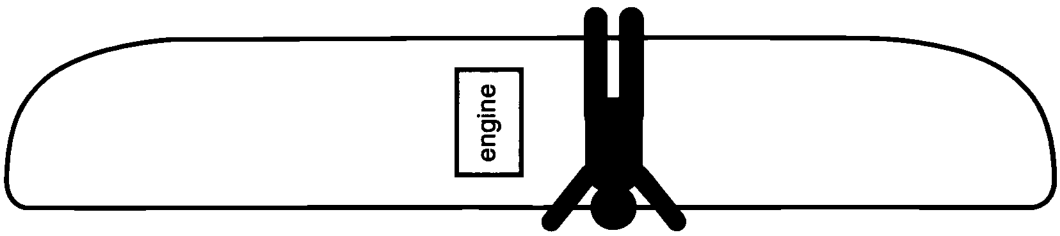
3. The Wright Brothers had to buy all the food to stock their camp and ship it by boat and horse-drawn wagon. In 1900, a loaf of bread cost 5 cents. Today it costs about $1, or 100 cents. The price of bread has increased by 100 cents divided by 5 cents, or 20 times. Find out how many times these items have increased in price since 1900 by completing the following table. You will need to find out today's prices.
   Here are some examples:

Food	1900 price	Price today	Increase
5 pounds flour	13 cents	**$1.65**	**12.7 times**
1 pound butter	26 cents	**$2.50**	**9.6 times**
1 dozen eggs	21 cents	**$1.25**	**6 times**
1 gallon milk	27 cents	**$2.50**	**9.3 times**

Which item showed the biggest change in price? **Flour**

Activity 17 answers

If you were either Orville or Wilbur Wright, and it came time to design a flying machine with an engine, where would you place the engine and where would you place the pilot? Do you think that the pilot should sit up or lie down on the wing? Don't forget that there had been numerous crashes in the brothers' gliders over the past 3 years. Give some serious thought to the reason or reasons for your decision.

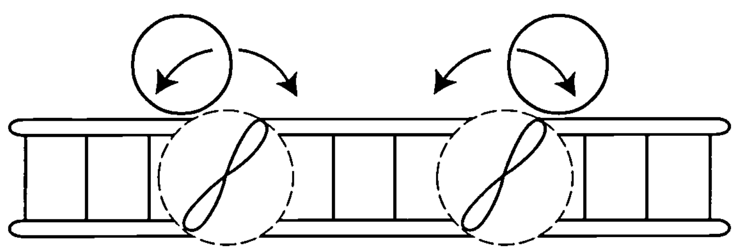


1. What are the advantages in the way you placed the engine and pilot?
   Student answers will vary. If the pilot and engine are placed side by side, this would be safer in a crash. If one is placed behind the other, this would allow for better balance in the aircraft.

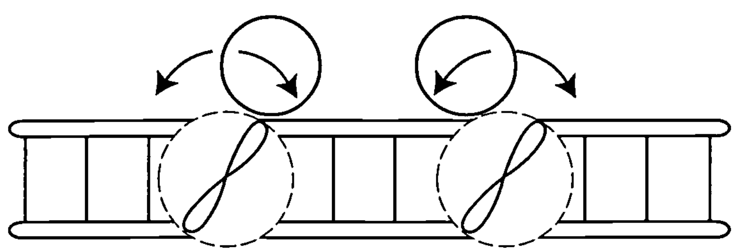
2. What problems do you think might be created with your placement?
   Side-by-side placement might create balance problems. If the pilot is in front of the engine, it might land on him in a crash. If the pilot is behind the engine, his vision might be blocked and he would have to sit up.

3. Does your pilot sit up or lay down?
   Varied answers.

4. Circle the direction that each propeller needs to turn to create the least amount of torque (twisting) of the aircraft.
   The propellers should turn in opposite directions, either both toward the center of the airplane (one clockwise and one counter-clockwise), or both outward, away from the nose of the airplane. Turning outward away from the nose is probably best. The contrary motion helps to cancel out the torque each propeller creates.



or



Activity 18 answers

In constructing their 1903 Flyer, the Wright Brothers chose to place the engine on the wing next to the pilot. They felt that this would be safer for the pilot because the engine would not land on him if the flyer crashed. The problem that this created for them was one of balance. Neither Wilbur nor Orville weighed as much as the engine, and the wings needed to be level in order to have control of the plane. Try the following activity to see how to solve the problem:

Take a string and tie it around a 12-inch ruler in the exact middle. Now hook two paper clips together to represent the pilot and four paper clips together to represent the engine. Open up one of the end paper clips on each group as shown so that they can hang on the ruler (you can also cut the paper clip to size with a wire cutter). Hook the groups on either side of the center and then slide the paper clips along the ruler until the ruler hangs level.

When the ruler is level, the total weight of one set of paper clips times the distance from the center is equal to the total weight of the other set of paper clips times their distance from the center. Write down the inch readings for each group of clips.

Two paper clips set at ___2___ inches from the center
Four paper clips set at ___4___ inches from the center

Since one group weighs twice as much as the other group, it should only be half as far from the center. Check the inch marks and see if this is true.
For any distance that the two paper clips are set, the four paper clips must be set half as far from the center.

The Wright Brothers needed to stay near the center of the plane in order to control it, so rather than move farther out on the wing to balance the engine, they made the wings on the engine's side of the plane 4 inches longer than on the pilot's side. This caused extra lift force on that side to counteract the extra weight of the engine and keep the wings level!

You can simulate this by moving the four-paper-clip weight 1/4 inch farther away from the center so things are no longer balanced. Now, instead of moving the two-clip weight to rebalance, move the location of the string holding the ruler until everything is back in balance. Did you move the string toward the two-clip weight or the four-clip weight? **Toward the four-clip weight.**

Activity 19 answers

Questions

1. Whose stick was the closest to the actual 120-foot mark? Do you think this is a very far distance to fly?
   Answers will vary. The Wright Brothers' flight was not a very far distance to fly.

2. Could the Wright Brothers have flown
   A. From home plate to first base on a baseball field? **Yes**
   B. From home plate to the outfield wall of the nearest professional baseball stadium? **No**
   C. From one wing tip of a Boeing 747 jumbo jet to the other? **No**
   D. From one goal line to the other goal line on a football field? **No**

3. Make a graph showing the distance from each person's marker to the actual 120-foot mark of the first flight. Did the group make good estimations of the distance? Find the average distance from the 120-foot mark.
   Answers will vary.

4. Make a graph showing how long it took each person to run 120 feet. Did the group run faster than the Wright Flyer flew? **Yes.** Find the average time for the group.

Math challenge

1. Your car can easily go 60 miles per hour and a jet airliner can cruise at 600 miles per hour. If the Wright Brothers flew 120 feet in 12 seconds on their first flight, calculate their speed in miles per hour.

   Hint: To do this you need to change feet to miles by dividing 120 feet by 5280, the number of feet in 1 mile. Then you need to change 12 seconds to minutes by dividing by 60, the number of seconds in 1 minute, and then change minutes to hours by dividing your last answer by 60, the number of minutes in 1 hour. Now divide the number of miles by the number of hours to find speed in miles per hour.

   6.82 miles per hour

   120 feet ÷ 60 seconds = .0227 miles

   12 seconds ÷ 60 seconds = .2 minutes

   .2 minutes ÷ 60 minutes = .00333 hours

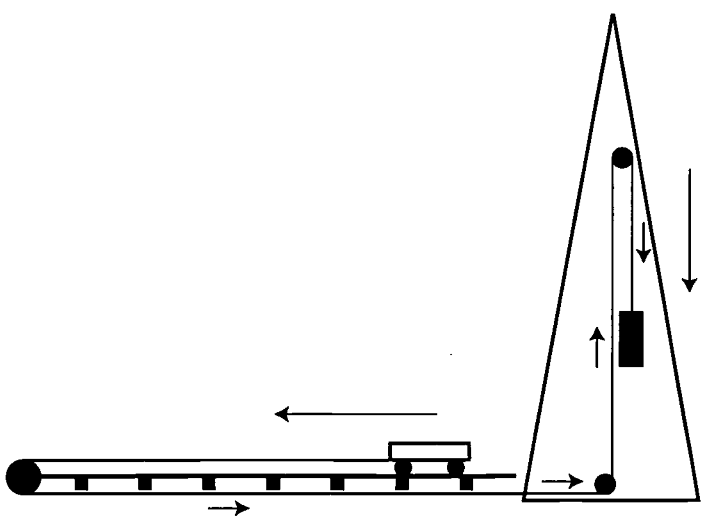
   .0227 miles ÷ .00333 hours = 6.82 miles per hour

You can also do the calculation by canceling units as shown below. Multiply the numbers on top and divide by the numbers on the bottom.

$$\frac{120\ \cancel{\text{feet}}}{12\ \cancel{\text{seconds}}} \times \frac{1\ \text{mile}}{5280\ \cancel{\text{feet}}} \times \frac{60\ \cancel{\text{seconds}}}{1\ \cancel{\text{minute}}} \times \frac{60\ \cancel{\text{minutes}}}{1\ \text{hour}} = 6.82\ \text{miles per hour}$$

Activity 20 answers

This diagram represents the derrick (shown on page 34) used to launch the 1904 Flyer, which would rest on the small wheeled trolley (or launch cradle) shown on the launch track. The problem is how to get the launch cradle to move forward when the weight drops. Can you draw ropes (lines) and pulleys (circles) in a way to make this happen? Draw arrows to show the direction each section of rope would move when the weight is dropped.



1. If the wind generally comes from the west, which way should the launch cradle travel?
   Toward the west, into the wind.

2. What are the difficulties in using this launch system? **Lifting the weight.**

3. Why didn't they just use the force from the flyer's propellers to take off like planes do today?
   The flyer's propellers couldn't produce enough thrust to take off, although they produced enough to fly.

Teacher Information

Activity 1: Early Aviation

Objective
The student will
1. Learn about the experiments of aviation pioneers
2. Recognize the requirements for gliding

National Science Standards
Understanding About Scientific Inquiry
Motions and Forces
Science as a Human Endeavor
History of Science

Description
The students pretend to be employed by the fictional "Cincinnati Scientific Society." They will look up information on aviation prior to 1900, write short paragraphs on early aviators, and answer some questions on their research.

Time requirements
40 minutes for research
20 minutes for writing

Materials
Library, reference books, and/or Internet access
Pencil and paper

Procedures
Students can research each topic or the work can be divided among groups and the results shared.

Background information
The Wright Brothers based their experiments on a body of knowledge collected by early aviators like Lilienthal and Chanute. The brothers were especially indebted to them for information on how to construct lightweight gliders. Curved wing surfaces, biplanes with wire bracing, and soft sand landing sites had all been used before 1900.

The German Otto Lilienthal was a respected aviator who built several successful gliders before being killed in flight. He had said, famously, "Sacrifices must be made." Lilienthal was the first to carry out glider experiments carefully and methodically, taking note of important data. He was a great inspiration to the Wrights.

Octave Chanute was a civil engineer and scientist who began to study the problems of flight later in life. He was a close friend and mentor to the Wright Brothers, guiding and encouraging them.

Samuel Langley was a physicist and astronomer who served for a time as secretary of the Smithsonian Institute. Langley succeeded in flying a steam-driven airplane model three-fourths of a mile in 1896 and received a Congressional grant of $50,000. His further attempts to fly were failures. It is said that the jeers of the newspapers and cynics crushed his spirit.

For further information, see http://wright.nasa.gov/researched.htm

Assessment activity
Check student answers against the Activity Answers section. Students may give their reports orally to the class.

Activity 2: Your First Interview

Objective
The student will
1. Determine what questions to ask in a fictional interview with the Wright Brothers

National Science Standards
Abilities of Technological Design
Science as a Human Endeavor
Nature of Science

Description
Students are to assume the role of a newspaper reporter and determine relevant questions to ask the Wright Brothers about their intended experiments. They will try to determine how the Wrights would answer their questions. Questions should center on the Wrights' motivation to learn how to fly.

Time requirements
20 minutes

Materials
Library, reference books, and/or Internet access
Pencil and paper

Procedures
The students write questions to ask the Wright Brothers. Students can research a single topic or the work can be divided among groups and the results shared.

Background information
(See pages 4, 5, and 8.)

Assessment activity
Students may compare their questions with a partner. The class may stage a mock interview using the questions and possible responses that they have prepared.

Activity 3: Your First Report

Objective
The student will
1. Learn why the Wright Brothers wanted to gain control of a craft in the air
2. Learn about the Wright Brothers and how they planned to do their work

National Science Standards
Form and Function
Motion and Forces
Abilities of Technological Design
Science as a Human Endeavor
Nature of Science

Description
Students meet the Wrights and gain a little insight into what they are intending to do through a "personal encounter" in the Wrights' bicycle shop.

Time requirements
20 to 25 minutes

Materials
Pencil and paper

Procedures
Students read "Meet the Wrights" on page 11.

Background information
The Wrights' early intentions were to add to the body of knowledge needed to eventually fly. They recognized that Lilienthal and others had been killed because they failed to control their machines. Their first goal was to learn to control a craft in the air and not be at the mercy of the wind. The brothers had tested their ideas on a large kite and then decided to construct a large, man-carrying glider in their bike shop to test at Kitty Hawk in North Carolina. (See pages 1 to 3.)

For further information, see http://wright.nasa.gov/airplane/kite00.html

Assessment activity
Students are to write a report on their "visit."

Activity 4: Build a Model of the 1900 Glider

Objective
The student will
1. Construct a scale model of the 1900 Wright Glider

National Science Standards
Form and Function
Abilities of Technological Design
History of Science

Description
Students read "1900: Kitty Hawk" on page 13 and then build a model of the Wrights' 1900 Glider to understand its size, scale, and function.

Time requirements
60 to 90 minutes

Materials
(See page 41.)

Procedures
(See page 41.)

Background information
You may decide to have students read the additional background information about the 1900 Glider on page 40 in connection with making the model. Try a local supermarket as a source for the Styrofoam trays.

Students have trouble setting the templates so the leading (front) edges of the wings curve downward. They will get the best results if they go step by step with the directions and pictures in the book.

Assessment activity
Compare models to pictures in activity book.

Activity 5: Questions on the 1900 Glider

Objective
The student will
1. Understand how the Wrights control their craft in the air
2. Recognize that testing models is a way to prove theories
3. Understand the advantages of testing at Kitty Hawk

National Science Standards
Evidence, Models, and Explanation
Change, Constancy, and Measurement
Form and Function
Motion and Forces
Abilities of Technological Design

Description
Students answer questions based on reading about an imaginary visit to the Wrights' 1900 camp at Kitty Hawk. The questions center on the factors that affect the flight of the glider.

Time requirements
10 minutes to read
15 minutes to answer the questions

Materials
Pencil and paper

Procedures
Students read "1900: Kitty Hawk" on page 13.

Background information
The students are "visitors" to the Wrights' 1900 experiments. Additional information on the 1900 Glider is available on page 40.

For further information, see http://wright.nasa.gov/airplane/air1900.html

Assessment activity
Students answers can be evaluated either in writing or in oral discussion.

Activity 6: What Would You Design?

Objective
The student will
1. Make design suggestions to increase lift

National Science Standards
Change, Constancy, and Measurement
Form and Function
Motion and Forces
Abilities of Technological Design

National Math Standards
Geometry
Measurement

Description
Having seen that the 1900 Glider has barely enough lift to carry a pilot, the students are asked to suggest how to redesign the glider. This also involves doing a dimensional drawing of their redesign.

Time requirements
60 minutes

Materials
Library, reference books, and/or Internet access
Pencil, ruler, and paper

Procedures
Students read "1900: Kitty Hawk" on page 13.

Background information
After their experiments in 1900, the Wrights realized that they needed to get more lift to be able to pilot a craft, so they redesigned their glider. You may wish to have the students do some research on factors affecting lift.

For further information, see http://wright.nasa.gov/airplane/liftold.html

Assessment activity
Students answers can be evaluated either in writing and drawing or in oral discussion. They can also present their designs to the class for discussion.

Activity 7: Build a Model of the 1901 Glider

Objective
The student will
1. Construct a scale model of the 1901 Wright Glider

National Science Standards
Form and Function
Abilities of Technological Design
History of Science

Description
Students read "1901: The First Improvement" on page 17 and then build a model of the Wrights' 1901 Glider to understand its size, scale, and function.

Time requirements
90 to 120 minutes

Materials
(See page 48.)

Procedures
(See page 48.)

Background information
You may decide to have students read the additional background information about the 1901 Glider on pages 46 and 47 in connection with making the model. Try a local supermarket as a source for the Styrofoam trays.

Students may have trouble setting the templates so the leading (front) edges of the wings curve downward. They will get the best results if they go step by step with the directions and pictures in the book.

Assessment activity
Compare models to pictures in activity book.

Activity 8: Forces on the 1901 Glider

Objective
The student will
1. Be able to recognize the four forces that act on an aircraft
2. Recognize that a change in a force will affect the position of the aircraft

National Science Standards
Evidence, Models, and Explanation
Motions and Forces

National Math Standards
Communicating
Geometry

Description
Using a picture of the 1900 Glider being flown as a kite, the students are asked to describe the forces that are acting upon it and to make a prediction about the results of changing one of the forces.

Time requirements
25 minutes

Materials
Library, reference books, and/or Internet access
Pencil, ruler, and paper

Procedures
The class may work on these questions individually or they can work in pairs or discussion groups.

Background information
The interactions of lift versus gravity forces and thrust versus drag forces are the core of this activity. These are vector forces, but are not presented as such. Since this exercise concerns a kite, which is affected by the static pull on its ropes to achieve balance in the wind, the forces are different than those on a glider or airplane. The main idea is that balance is maintained through opposing forces.

For further information, see http://wright.nasa.gov/airplane/kitefor.html

Assessment activity
Students should compare their drawings to the actual answers.

Activity 9: Questions on the 1901 Glider

Objective
The student will
1. Be able to suggest reasons for the problems with the 1901 Glider design
2. Learn about a scientific method of conducting experiments
3. Recognize that it is important to for scientists to learn from failures and continue trying

National Science Standards
Evidence, Models, and Explanation
Understanding About Scientific Inquiry
Science as a Human Endeavor

Description
Having read about the 1901 experiments, the students are asked to propose reasons why the larger wings may have generated less lift. They are also asked what a scientist might do to solve the problem, and to suggest what course the Wrights should take at this point.

Time requirements
20 minutes

Materials
Pencil and paper
Reference books and/or Internet access

Procedures
The class may work on these questions individually or they can work in pairs or discussion groups.

Background information
The Wrights realized that there was a factor or factors that they were not considering in trying to generate lift. They were on the verge of giving up when they decided to reevaluate their data and build a wind tunnel. The Wrights, like scientists today, were careful to change just one variable at a time to note the effect of each change separately. This is an important point to make with students. It is also important that this experiment, like most experiments, did not work as expected the first time. The Wright Brothers worked through their failures until they eventually succeeded.

For further information, see http://wright.nasa.gov/airplane/test1901.html

Assessment activity
Students should be able to discuss their answers and give reasons and evidence for their choices.

Activity 10: Wrong Ideas

Objective
The student will
1. See that incorrect assumptions can lead to wrong ideas and conclusions
2. Recognize that incorrect ideas are sometimes widely accepted as correct

National Science Standards
Understanding About Scientific Inquiry
Nature of Science
History of Science

Description
In this activity the students research some wrong ideas that at one time were thought to be correct.

Time requirements
45 minutes

Materials
Library, reference books, and/or Internet access
Pencil and paper

Procedures
The students need to research the origins of some scientific theories that were once accepted as correct.

Background information
Throughout history people have had to change their ideas about the way the world worked when new evidence was presented. Many times in the past, ideas have been accepted as true on the basis of authority or reputation, religious beliefs, or just bad measurements.

The Wright Brothers also had to "question authority." The accepted data of the time that they were using simply did not give the results they expected. Because the data came from Otto Lilienthal, the preeminent authority on aeronautics, the Wrights assumed that they were correct. Ultimately, the brothers conducted their own wind tunnel tests to determine what was wrong.

In fact, there were two sources of errors in the Wrights' initial design calculations. There was a pressure coefficient, called "Smeaton's coefficient," which was used as the reference for published aerodynamic data at the time. The Wrights used the accepted value for this coefficient, as did Lilienthal. But there was a large error in the value of the coefficient because it is a very difficult measurement to make accurately. The brothers discovered the error and derived a more accurate value.

The second error was in the use of Lilienthal's lift coefficients. The brothers did not understand the important effects of wing planform shape on lift until they conducted their wind tunnel tests. The planform is the shape of the wing when viewed looking down onto the wing. Lilienthal had tested his models as small oval shapes, and the brother's wings were rectangles. The difference in shape makes a difference in the amount of lift generated. Wilbur writes, "Any table (of lift) is liable to great misconstruction if the surface to which it is applicable is not clearly specified." The brothers' actually tested Lilienthal's shape and found that his data was "... as near correct as it is possible to make it with the methods he used."

—Wilbur Wright, from a 1901 letter to Octave Chanute.

For further information, see http://wright.nasa.gov/airplane/smeaton.html and http://wright.nasa.gov/airplane/models.html

Assessment activity
Students present their results to the class for discussion.

Activity 11: The Wrights' Wind Tunnel

Objective
The student will
1. Be able to describe the function of a wind tunnel and point out how its parts operate
2. Understand that a wind tunnel can be used to collect data under controlled conditions that can be applied on a larger scale

National Science Standards
Evidence, Models, and Explanation
Change, Constancy, and Measurement
Form and Function
Abilities of Technological Design

Description
This activity is designed to show students how a wind tunnel can be used to collect aeronautical data. Students learn that procedures used by the Wrights are still used in wind tunnels today.

Time requirements
45 minutes

Materials
Library, reference books, and/or Internet access
Pencil and paper

Procedures
The students read "New Data" on page 20 prior to answering the questions.

Background information
Orville and Wilbur's tunnel was not the first wind tunnel ever constructed, but it was the first that gave accurate and useful data. It was also the first tunnel that could be used to verify earlier testing results and design future aircraft. For a wind tunnel to give accurate information, the flow of air needs to be as free of turbulence as possible, so the brothers used grids to straighten the airstream. Students should recognize that testing small-scale models saves time and expense.

For further information, see http://wright.nasa.gov/airplane/tunnel.html

Assessment activity
Check student answers against the Activity Answers section.

Activity 12: Operate the Wrights' Tunnel

Objective
The student will
1. Become more familiar with how a wind tunnel operates
2. Recognize that some wing forms give better lift
3. Understand how the Wrights gathered data from wind tunnel experiments

National Science Standards
Evidence, Models, and Explanation
Change, Constancy, and Measurement
Form and Function
Understanding Scientific Inquiry
Abilities of Technological Design
Nature of Science

National Math Standards
Communication
Numbers and Number Relationships
Patterns
Statistics
Geometry
Measurement

Description
Students operate a virtual Wright wind tunnel on a computer and collect data on a variety of wing forms actually used by the Wrights.

Time requirements
45 minutes

Materials
Internet access
Pencil

Procedures
Students print out a data form and then follow a set of activities in which they compare different aspects of wing design. They graph their results to draw conclusions.

Background information
The simulation in this activity operates in the same way as the Wrights' original tunnel. The student can choose from any of the wing shapes tested by the Wrights (taken from the actual models now housed in the Franklin Institute in Philadelphia) and collect data in the same way they did. The student places a wing model in the tunnel, starts the fan, and then adjusts for the drag caused by the balance itself. The angle is read and the data graphed. The students should discover that long, thin wings give the best results.

For further information, see http://wright.nasa.gov/airplane/tunnlint.html

Assessment activity
The students could be given several of the wing forms at random and asked to comment on which might give the best results based on the data they have just collected. They can also compare graphs and discuss the best results.

Activity 13: Build a Model of the 1902 Glider

Objective
The student will
1. Construct a scale model of the 1902 Wright Glider

National Science Standards
Form and Function
Abilities of Technological Design
History of Science

Description
Students read "1902: Success at Last" on page 25 and then build a model of the Wrights' 1902 Glider to understand its size, scale, and function.

Time requirements
120 minutes

Materials
(See page 55.)

Procedures
(See page 55.)

Background information
You may decide to have students read the additional background information about the 1902 Glider on page 54 in connection with making the model. Try a local supermarket as a source for the Styrofoam trays.

Students have trouble setting the templates so the leading (front) edges of the wings curve downward. They will get the best results if they go step by step with the directions and pictures in the book.

Assessment activity
Compare models to pictures in activity book.

Activity 14: Compare the 1900, 1901, and 1902 Gliders

Objective
The student will
1. Be able to list similarities and differences in the first three Wright gliders
2. Recognize the relationship between wing shape and performance

National Science Standards
Evidence, Models, and Explanation
Form and Function
Motions and Forces
Abilities of Technological Design

National Math Standards
Geometry

Description
Drawings of the 1900, 1901, and 1902 gliders are shown on page 26 at the same scale for the purpose of comparison. Students are asked to list similarities and differences and then speculate about reasons for the 1902 success.

Time requirements
25 minutes

Materials
Pencil

Procedures
The students compare glider features.

Background information
With each gliding season, the Wrights arrived at Kitty Hawk with a redesigned glider. When the 1900 Glider proved barely able to lift itself with a pilot, the brothers designed a glider with much greater wing surface in 1901, trying to create more lift. It turned out that this glider, although able to carry a pilot more easily, only produced about one-third of the expected lift. On the verge of giving up, the Wrights conducted wind tunnel tests during the winter of 1901 and determined that they had made the wrong choice with the 1901 Glider. Instead of short, wide wings, they should have made long, thin wings. The 1902 Glider had long, thin wings of nearly the same wing area as the 1901 Glider, but it set world records for gliding.

For further information, see http://wright.nasa.gov/airplane/air1902.html

Assessment activity
Students should be able to point out how the 1902 design differed from the previous gliders.

Activity 15: Prices Then and Now

Objective
The student will
1. Gain perspective on the relative costs of goods over a 100-year period
2. Be able to calculate percentages based on real data

National Science Standards
Change, Constancy, and Measurement
Understanding About Scientific Inquiry

National Math Standards
Problem Solving
Math Connections
Computation and Estimation

Description
Since Orville Wright recorded the brothers' experiments with a box camera, 1900 prices are given for cameras as well as for several common items. The activity has students calculate the percentage of a salary to buy a camera then and now. It also has the students compare how the prices on a number of common items have risen since 1900.

Time requirements
30 minutes

Materials
Pencil, paper, and calculator

Procedures
The students collect data on some food costs today, compare them to food costs in 1900, and calculate the percentage change. They also calculate the percentage of a monthly salary needed to buy a camera in 1900 and today.

Background information
Orville took and developed a large number of pictures of the brothers' experiments to document their results. The glass negatives were developed back in Dayton, where large numbers of them remain today. All of the Wrights' experiments through 1903, including travel, cost them about $1,200.

Assessment activity
Students should be able to calculate percentage increases. Teachers might want to have students put their problems on the chalkboard.

Activity 16: Build a Model of the 1903 Flyer

Objective
The student will
1. Construct a scale model of the 1903 Wright Flyer

National Science Standards
Form and Function
Abilities of Technological Design
History of Science

Description
Students read "1903: Powered Flight" on pages 28 and 29 and then make a model of the Wrights' 1903 Flyer to understand its size, scale, and function.

Time requirements
120 minutes

Materials
(See page 63.)

Procedures
(See page 63.)

Background information
You may decide to have students read the additional background information about the 1903 Flyer on page 62 in connection with making the model. Try a local supermarket as a source for the Styrofoam trays.

Students have trouble setting the templates so the leading (front) edges of the wings curve downward. They will get the best results if they go step by step with the directions and pictures in the book.

Assessment activity
Compare models to pictures in activity book.

Activity 17: Balancing Forces

Objective
The student will
1. Understand some of the challenges of making a powered flying machine

National Science Standards
Evidence, Models, and Explanation
Form and Function
Understanding About Scientific Inquiry
Motions and Forces
Abilities of Technological Design

Description
The students need to propose solutions to engine and pilot placement problems and also choose how to cancel the torque (twist) produced by two rotating propellers.

Time requirements
20 minutes

Materials
Pencil

Procedures
The students plot the location of the pilot and engine on the wing of the 1903 Flyer. They need to justify their placement, especially in terms of safety and balance.

Background information
Having crashed a number of times over the years, the Wrights were concerned about crashing into a hot engine or having the engine crash onto them. With this in mind, they put the engine on the wing beside the pilot. This created a balance problem because the engine was heavier than either Wilbur or Orville. To compensate for the extra weight, the brothers made the wing on the engine side 4 inches longer to add extra lift on that side and balance the plane.

They also made the propellers turn in opposite directions to have them cancel out each other's torque. To make this happen, they twisted one of the chains used to turn the propellers into a figure eight. This made the corresponding propeller rotate in the opposite direction.

For further information, see http://wright.nasa.gov/airplane/propeller.html

Assessment activity
Students should put the pilot next to the engine and have the propellers rotating in opposite directions.

Activity 18: Center of Gravity

Objective
The student will
1. Understand how balance is a function of both mass and distance from the center of rotation

National Science Standards
Evidence, Models, and Explanation
Change, Constancy, and Measurement
Understanding About Scientific Measurement
Motions and Forces

National Math Standards
Reasoning
Math Connections
Patterns
Measurement

Description
This is a followup to Activity 17 and deals with balancing the aircraft. The students balance paper clips on a ruler and investigate the relationship between mass and distance from the center.

Time requirements
30 minutes

Materials
String, 12-inch ruler, and paper clips

Procedures
The students attempt to keep a ruler hanging from a string level by sliding paper clips out from the center.

Background information
This activity takes patience and small adjustments. Students often have difficulty with this and may need assistance to get good results.

For further information, see http://wright.nasa.gov/airplane/cg.html

Assessment activity
Students should be able to tell how far from the center one must hang one paper clip (6 inches) to balance three paper clips hanging on the other side located 2 inches from the center.

Activity 19: How Far Did They Fly?

Objective
The student will
1. Estimate a distance of 120 feet
2. Realize how slow the Wrights flew at first
3. Collect and graph data
4. Calculate speed by dividing distance by time

National Science Standards
Change, Constancy, and Measurement
Understanding About Scientific Inquiry

National Math Standards
Problem Solving
Math Connections
Computation and Estimation

Description
Students try to estimate the distance that Orville Wright first flew. Then they find out how long it takes them to run this distance. They graph both results for discussion.

Time requirements
45 minutes to collect data
45 minutes to graph and answer questions

Materials
Library, reference books, and/or Internet access
Pencil, paper, ruler, and calculator
Craft sticks or other devices to mark distances
Measuring tape (the longer the better)
Timer to measure seconds
150-foot string (optional)

Procedures
Students estimate the distance of 120 feet down a line or string and place their marker at their estimate. Then the actual 120-foot distance is measured and the distance from each marker to the true 120-foot distance is measured and recorded. After the students pick up their markers, each student is timed as he or she runs 120 feet and this time is recorded. Students will need to measure several familiar distances to get a relative sense of scale (such as the length from home to first base on a baseball diamond, the length of a familiar hall at school, etc.).

Background information
Orville flew an estimated 12 seconds (he forgot to start the watch!) and landed 120 feet from the starting point. This was not far for an airplane flight, especially by today's standards. The students should realize that this is the case and they should see that they can run faster than the flyer flew.

Assessment activity
Check student answers against the Activity Answers section.

Activity 20: How to Launch the Flyer

Objective
The student will
1. Be able to show how to change the direction of a force
2. Recognize the advantage of launching into the wind

National Science Standards
Evidence, Models, and Explanation
Transfer of Energy
Motions and Forces

Description
Students are asked to complete a diagram of how the Wrights launched their flyer using a falling weight.

Time requirements
20 minutes

Materials
Pencil

Procedures
The students draw the ropes and pulleys that will correctly transfer the force of the falling weight.

Background information
Once the Wrights had a powered flyer, they decided they did not need to journey to North Carolina to get sufficient wind for testing. However, although the Wright Flyer could sustain itself in the air, it still lacked the power for an unassisted take-off. They solved this problem by using the energy from a falling weight. Launching into the wind added extra lift.

For further information, see http://wright.nasa.gov/airplane/air1905.html

Assessment activity
Check student answers against the Activity Answers section.

Activity 21: Write a Press Release

Objective
The student will
1. Be able to use what he or she has learned about the Wright's efforts to write a factual press release

National Science Standards
Abilities of Technological Design
Science as a Human Endeavor

Description
Students take on the role of an eyewitness to the Wright Brothers' experiments and are asked to turn their "observations" into a press release.

Time requirements
30 minutes

Materials
Pencil and paper

Procedures
Students review their observations of the Wright Brothers' experiments in the booklet and write a press release.

Background information
In 1903, to be prepared, the Wrights wrote their own press release in advance of their first successful flight. When they telegraphed their success to their sister Katharine, she took it to the local papers. Very little was printed at the time because, as one editor put it, "Had they flown for 12 minutes instead of 12 seconds, that would have been news."

Assessment activity
Have students pose as newspaper editors to select the best press releases to print.

Activity 22: Design a Mission Patch

Objective
The student will
1. Be able to relate a design to the Wrights' achievement

National Science Standards
Science as a Human Endeavor

Description
Since all NASA missions are commemorated with a patch, the students are asked to design a Wright Brothers patch.

Time requirements
30 to 45 minutes

Materials
Colored pencils, crayons, markers, and paper

Procedures
Students can review NASA patches for ideas. They should then draw their own patch for the Wright Brothers. The shape and content is up to the student.

Background information
The Web site shows all the patches for the NASA missions. Patches can also be obtained from NASA visitor centers.

Assessment activity
Displays should be made of student work.

Activity 23: Be an Inventor

Objective
The student will
1. Understand that invention requires imagination
2. Realize that inventors always face difficulties

National Science Standards
Understanding About Scientific Inquiry
Abilities of Technological Design
Science as a Human Endeavor

Description
Having followed the Wrights' invention process, students are asked to use their imaginations to propose an invention to improve transportation.

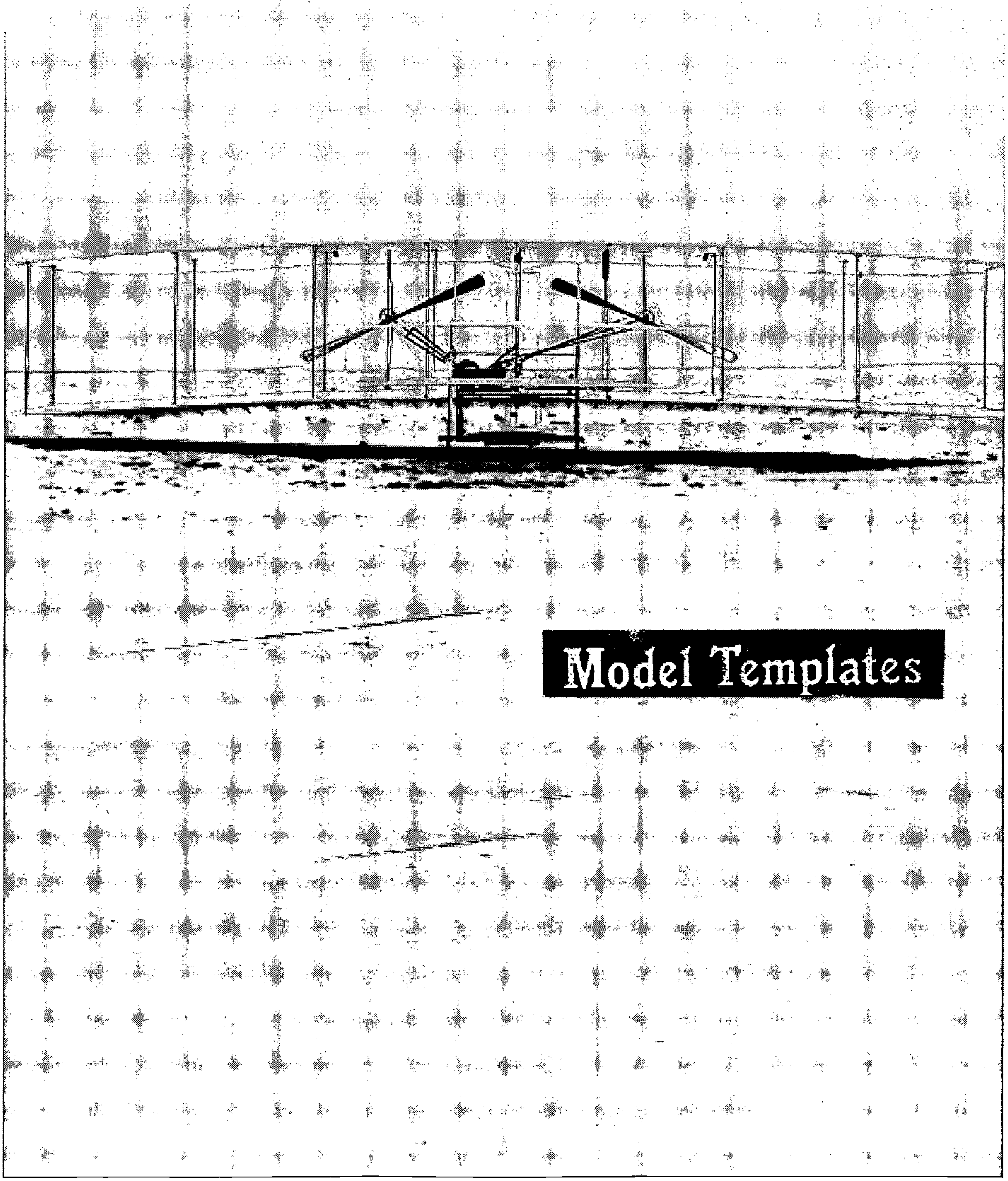
Time requirements
45 minutes

Materials
Pencil and paper

Procedures
Students can review the Wright Brothers' "observations" of their experiments in the booklet, and then write about something they would like to invent to improve transportation. They should consider problems they may encounter and decide how to publicize their efforts.

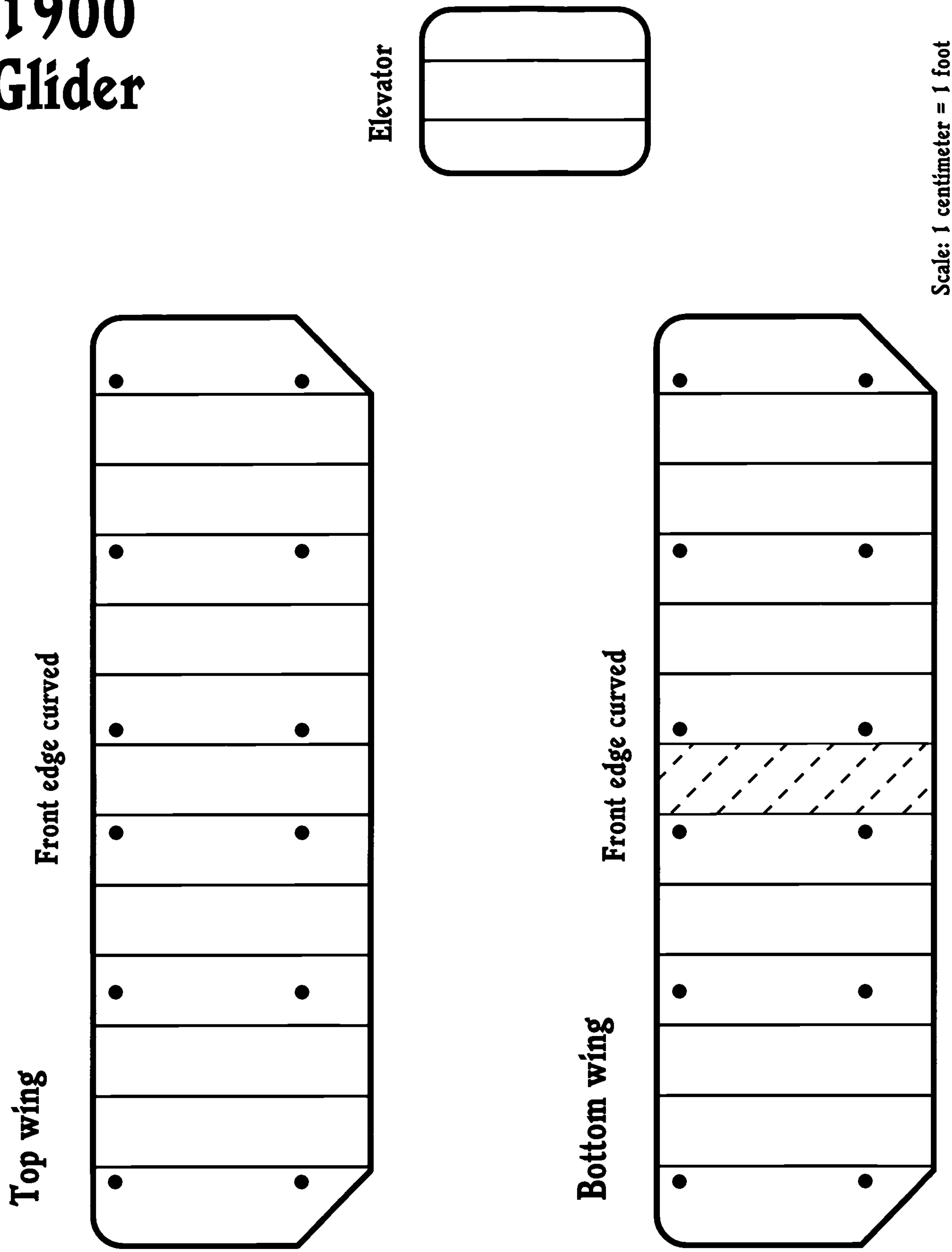
Background information
The invention process can be difficult for children. Emphasize to them that anything is possible and tell them not to limit their thinking. However, they should consider such things as cost and safety when they evaluate their ideas.

Assessment activity
Have students share their ideas and sketches with the class and let the class choose those that they think would be the most successful.

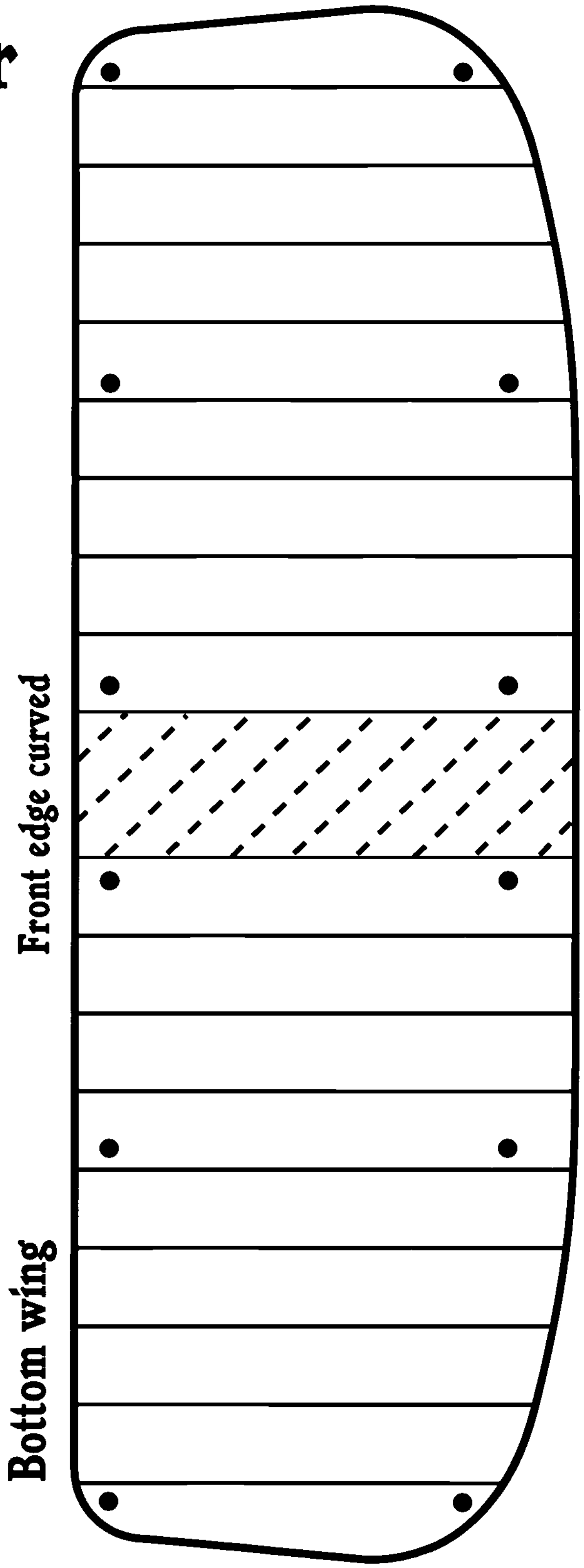


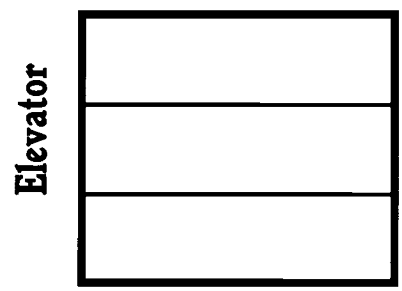
Model Templates

1900 Glider


Elevator
Scale: 1 centimeter = 1 foot
Front edge curved
Top wing
Front edge curved
Bottom wing

1901 Glider

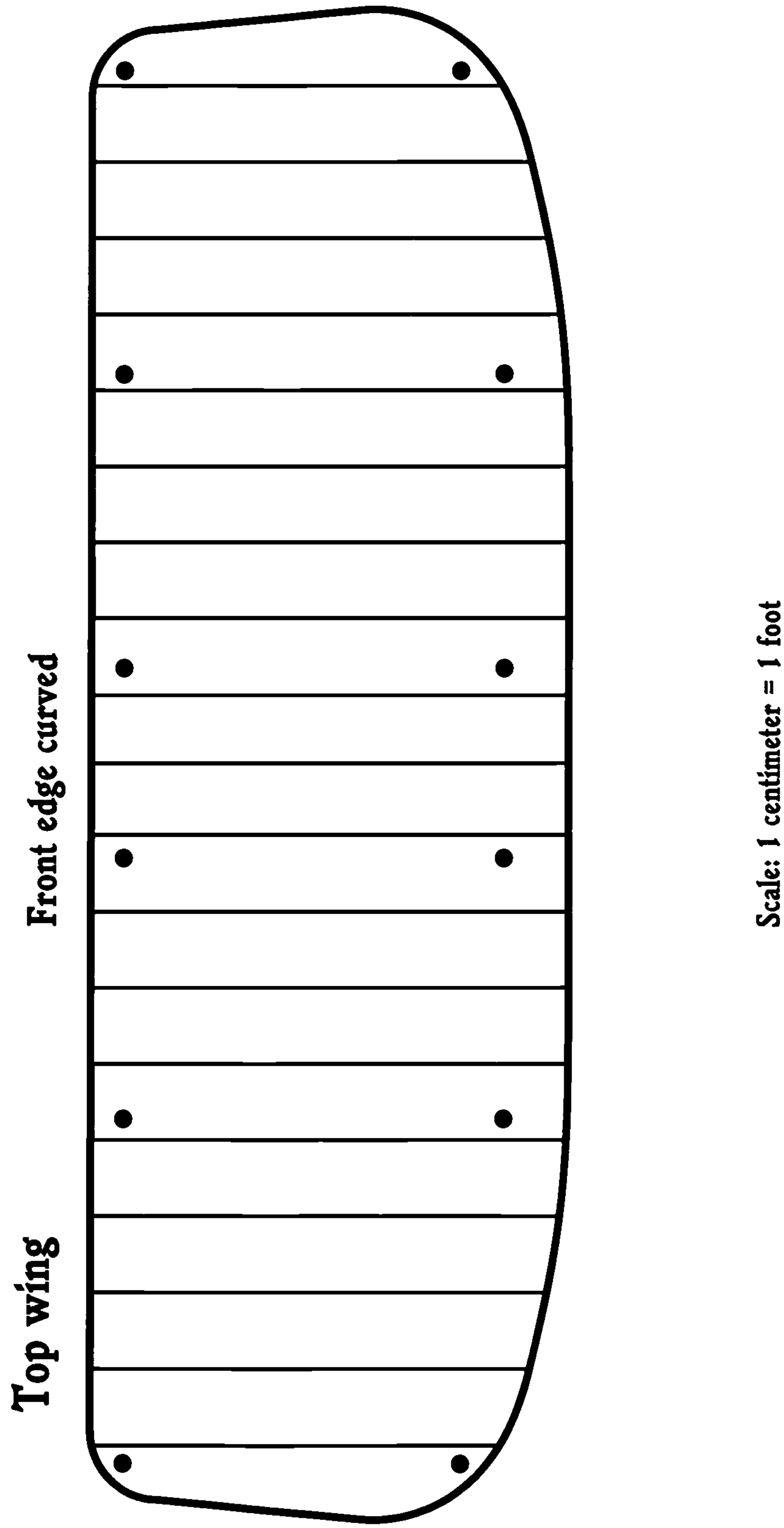




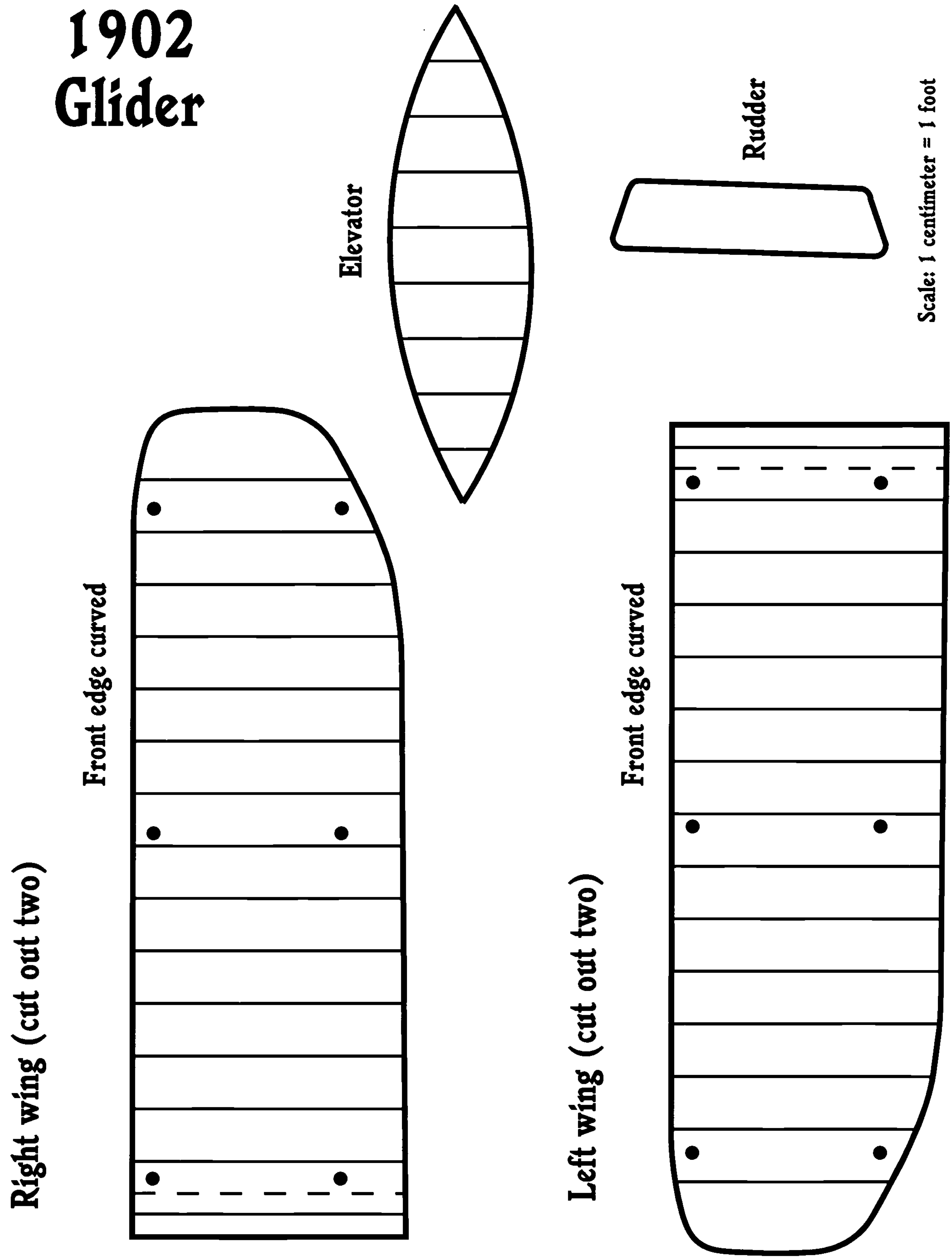
Scale: 1 centimeter = 1 foot

Continued on following page

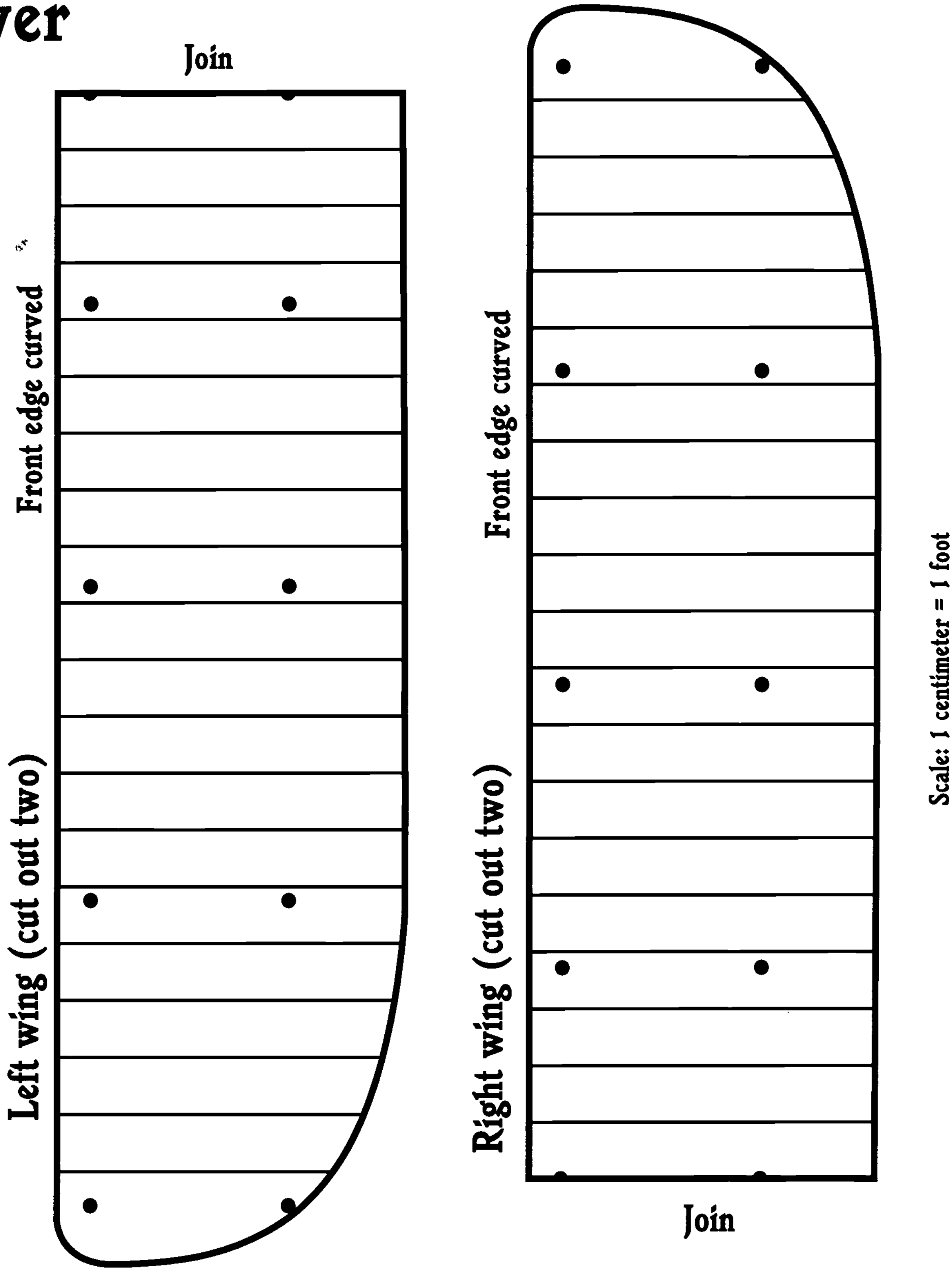
1901 Glider



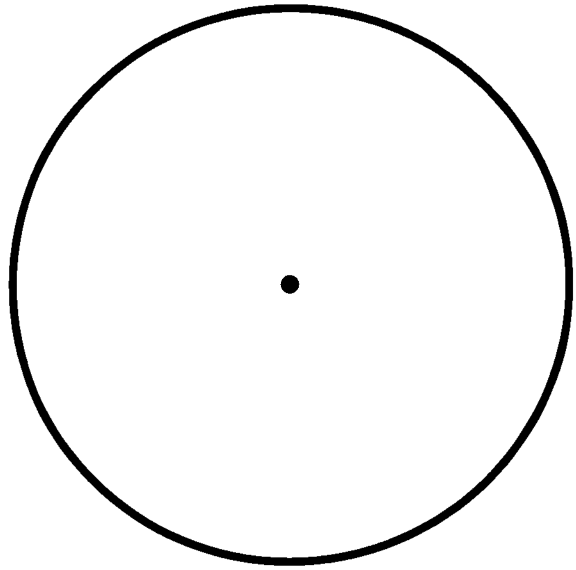
1902 Glider


Elevator
Rudder
Scale: 1 centimeter = 1 foot
Front edge curved
Right wing (cut out two)
Front edge curved
Left wing (cut out two)

1903 Flyer

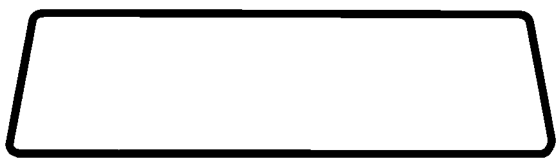

Join
Front edge curved
Left wing (cut out two)
Front edge curved
Right wing (cut out two)
Join
Scale: 1 centimeter = 1 foot

1903 Flyer

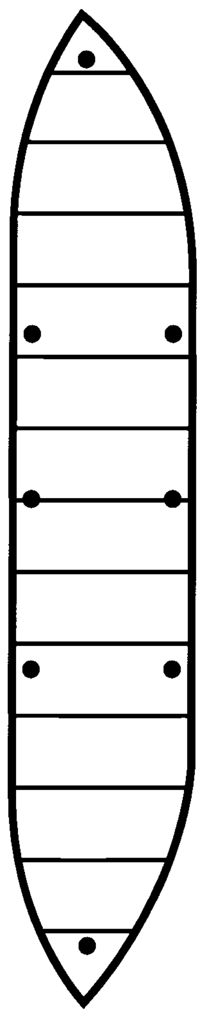


Propeller circle
(cut out two)

Propeller (cut out two)



Rudder (cut out two)



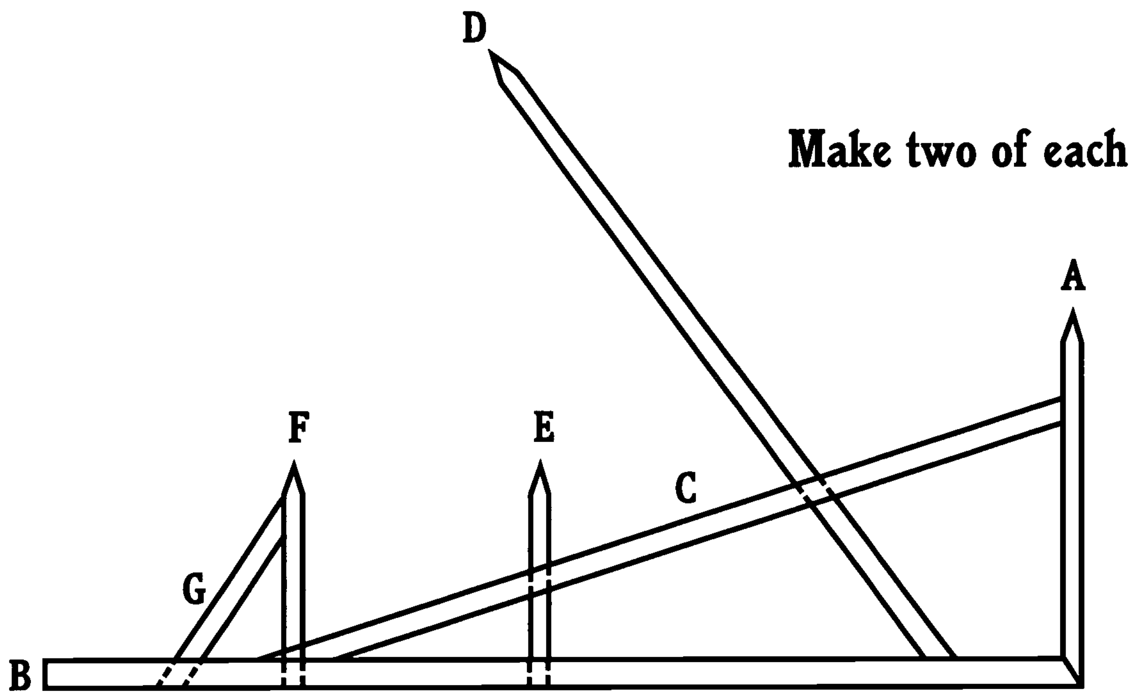
Elevator (cut out two)

Front edge curved

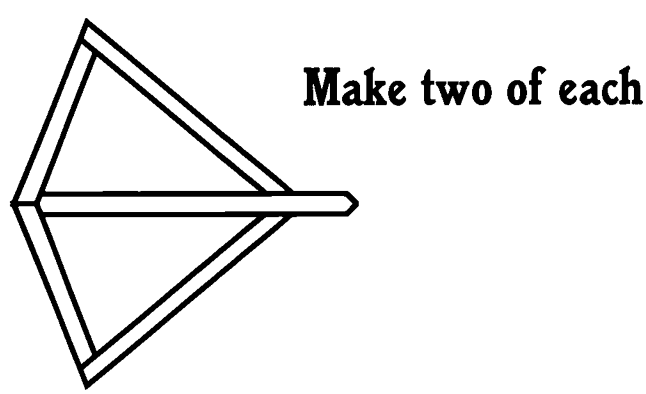
Scale: 1 centimeter = 1 foot

1903 skids template

(3 long pieces of balsa wood)



1903 propeller template



B–1001
Feb 03

Learning To Fly: The Wright Brothers' Adventure
An Inquiry-Based Technology Educator Guide

EDUCATOR REPLY CARD

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Send your reply to the following Internet address:

https://ehb2.gsfc.nasa.gov/edcats/educator_guide

You will then be asked to enter your data at the appropriate prompt.

Otherwise, please return this reply card by mail. Thank you.

1. With what grades did you use the educator guide?
   Number of teachers/faculty:

   _____ K–4 _____ 5–8 _____ 9–12 _____ Community college

   _____ College/University - Undergraduate _____ College/University - Graduate

   Number of students:

   _____ K–4 _____ 5–8 _____ 9–12 _____ Community college

   _____ College/University - Undergraduate _____ College/University - Graduate

   Number of others:

   _____ Administrators/staff _____ Parents _____ Professional groups

   _____ General public _____ Civic groups _____ Other

2. What is your home five- or nine-digit zip code? _ _ _ _ _ - _ _ _ _

3. Is this a valuable educator guide?

   ❑ Strongly agree ❑ Agree ❑ Neutral ❑ Disagree ❑ Strongly disagree

4. I expect to apply what I learned in this educator's guide.

   ❑ Strongly agree ❑ Agree ❑ Neutral ❑ Disagree ❑ Strongly disagree

Fold along line and tape closed.

5. What kind of recommendation would you make to someone who asks about his educator's guide?

   ❑ Excellent ❑ Good ❑ Average ❑ Poor ❑ Very Poor

6. How did you use this educator guide?

   ❑ Background information
   ❑ Demonstrate NASA materials
   ❑ Group discussions
   ❑ Integration into existing curricula
   ❑ Lecture
   ❑ Team activities
   ❑ Other - Please specify: ____________
   ❑ Critical thinking tasks
   ❑ Demonstration
   ❑ Hands-on activities
   ❑ Interdisciplinary activities
   ❑ Science and mathematics
   ❑ Standards integration

7. Where did you learn about this educator's guide?

   ❑ NASA Educator Resource Center
   ❑ NASA Central Operation of Resources for Educators (CORE)
   ❑ Institution/school system
   ❑ Fellow educator
   ❑ Workshop/conference
   ❑ Other - Please specify: ____________

8. What features of this educator's guide did you find particularly helpful?

   ____
   ____
   ____

9. How can we make this educator's guide more effective for you?

   ____
   ____
   ____

10. Additional comments:

   ____
   ____
   ____

Today's date: ____________

B–1001a
Feb 03

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